Queen Margaret University

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## SCHOOL OF HEALTH SCIENCES

# WHOLE BODY VIBRATION EXERCISES FOR CHILDREN WITH CEREBRAL PALSY

**MSc. Advancing Physiotherapy Practice 2018**

# WHOLE BODY VIBRATION EXERCISES FOR CHILDREN WITH CEREBRAL PALSY.

This dissertation is submitted in part fulfilment of the award of the degree of Master of Science Advancing Physiotherapy Practice.

Queen Margaret University

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# ABSTRACT

**Background:** Cerebral Palsy (CP) is defined as long-lasting non-progressive damage to the foetal or developing brain which may affect the individual's movement and posture. A new physiotherapy intervention has been introduced in order to help treat children with CP which is called Whole Body Vibration (WBV). WBV helps to improve walking, muscle strength, bone mineral density (BMD), decrease tone and improve motor function in children with CP. However, research into the effectiveness of WBV has produced inconsistent results. An up-to-date systematic review is therefore necessary to appraise and synthesise all the available evidence.

**Objective:** The aim of this systematic review was to evaluate the effectiveness of WBV exercises in children with CP on strength, walking, function, bone mineral density (BMD) and spasticity.

**Search Strategy:** Five databases were searched during the month of May 2018 using a pre-determined selection of key words. The databases were: Cochrane Library, PubMed, CINAHL Plus with Full Text, MEDLINE and PEDro. The reference lists of all articles selected for inclusion were also searched to identify any additional studies.

**Selection Criteria:** All randomised controlled trials (RCTs) including randomized cross-over trials were included in this systematic review.

**Data Collection and Analysis:** The articles were selected based on the inclusion criteria. The methodological quality of all the final selected studies was assessed using The Cochrane Risk of Bias Tool.

**Results:** Twelve articles were selected for inclusion in this review. The results of all six studies that focused on walking indicated that WBV has a positive effect on walking in children with CP

who either walk alone or with a walking aid. Similarly, improvement in strength was found in four studies out of five, improvement in BMD was found in two studies out of only three and improvement in spasticity was found in three studies only. Four studies focusing on function resulted in an equal amount of conflicting results. The methodological quality of the studies included was variable.

**Conclusion:** Results of the selected studies suggest that WBV as an adjunct to other treatment may improve walking who can walk with or without a walking aid. It may also improve muscle strength in children with CP. WBV may also improve spasticity and BMD. However, further high quality research is recommended to validate improvement in muscle strength, spasticity and BMD. Conflicting evidence for function has been found, therefore, further high quality studies are also recommended to investigate this further.

# CONTENTS

Copyright……i

Acknowledgements……ii

Abstract……iii

1.Introduction ..... 7

2. Background and Rationale ..... 10

2.1 Background ..... 10

2.1.1 Pathology and types of Cerebral Palsy ..... 10

2.1.2 Clinical Features of Cerebral Palsy ..... 11

2.1.3 Whole Body Vibration ..... 12

2.1.4 Physiological Effects of Whole Body Vibration ..... 12

2.2. Rationale of the Study ..... 13

2.3 Conclusion ..... 14

3.1 Aim ..... 16

3.2 Objectives ..... 16

3.3 The PICO Framework used in this study ..... 16

4. Methodology ..... 19

4.1 Databases Search ..... 19

4.2 Key Words ..... 20

4.3 Inclusion and Exclusion Criteria ..... 23

4.3.1 Report characteristics ..... 23

4.3.2 Study Characteristics ..... 24

4.4 Study Selection ..... 29

4.5 Quality Assessment....30
4.6 Data Extraction and analysis....30
5. Results....34
5.1 Electronic database searches and study selection results....34
5.2 Description of included studies....39
5.2.1 Study Designs....39
5.2.2 Study Aims....39
5.2.3 Sample Recruitment....50
5.2.4 Sample Characteristics....50
5.2.5. Ethics approval and consent....54
5.3 Interventions....54
5.3.1. WBV Protocol/Procedure....62
5.3.2 Duration of interventions and sessions....62
5.3.3. Frequency of interventions....62
5.3.4 Intervention parameters....63
5.4 Control intervention/comparison....63
5.5 Types of Outcome Measures....63
5.5.1 Strength....64
5.5.2 Walking....64
5.5.3 Function....65
5.5.4 Bone Mineral Density (BMD)....65
5.5.5 Spasticity....65
5.5.6 Additional Outcome Measures....65
5.6 Quality Assessment of Selected Studies....66
5.7 Study Results....69
5.7.1 Strength....69

5.7.2 Walking ..... 69
5.7.3 Function ..... 71
5.7.4 BMD ..... 71
5.7.5 Spasticity ..... 72
5.8 Summary of Results and Risk of Bias ..... 72
5.9 Conclusion ..... 75
6. Discussion ..... 77
6.1 Synthesis of the results ..... 77
6.1.1 Strength ..... 77
6.1.2 Walking ..... 78
6.1.3 Function ..... 79
6.1.4 BMD ..... 80
6.1.5 Spasticity ..... 81
6.2 Blinding of Participants and Assessors ..... 83
6.3 Recruitment ..... 83
6.4 Sample size ..... 83
6.5 Differences between Included Studies ..... 84
6.6 Strengths and limitations of the review ..... 84
6.7 Implications for practice and future research ..... 85
7.1 Conclusion ..... 88
8. References ..... 90
9. Appendices ..... 104
Appendix 1: The Cochrane Risk of Bias Assessment Tool ..... 104
Appendix 2: Risk of Bias Assessments ..... 105

## List of figures

Figure 1: The pyramid of evidence-based medicine……...24

Figure 2: Flow chart of the entire literature search and the study selection process……...38

## List of tables

Table 1: The PICO framework……17

Table 2: The key terms used for the literature search…..……..21

Table 3: Template used for the documentation of the search streategy…..……22

Table 4: Outcomes and examples of how they will be measured…….……..28

Table 5: A summary of the inclusion and exclusion criteria used in this study……..29

Table 6: Template of the summary of sample characteristics…….……....31

Table 7: Template of the summary of WBV parameters…….……..…31

Table 8: Template of the summary of study design, study aims, outcome measure(s), results and conclusion of selected studies……..……..……..……..……32

Table 9: Record of electronic search of databases……..……..……..……..36

Table 10: Studies excluded from systematic review…….……..……..…37

Table 11: Summary for the data extraction of the study design, outcome measure(s), results and conclusion of selected studies…….……..……..……..……40

Table 12: Summary of sample characteristics…….……..……..……52

Table 13: Summary of the intervention, control and procedure/protocol used……..…55

Table 14: Risk of bias assessment results…….……..……..……..…68

**List of abbreviations**.....**5**

## List of abbreviations

AROM – Active Range of Motion

BMD – Bone Mineral Density

CINAHL - Cumulative Index for Nursing and Allied Health Literature

CP – Cerebral Palsy

GMFCS – Gross Motor Function Classification System

GMFM – Gross Motor Function Measure

MAS – Modified Ashworth Scale

MeSH - Medical Subject Headings MMAS – Modified Modified Ashworth Scale

PROM – Passive Range of Motion

RCT – Randomised Controlled Trial

TUG – Timed Up and Go test

WBV – Whole Body Vibration

# 1. INTRODUCTION

# 1. INTRODUCTION

Cerebral Palsy (CP) is defined as long-lasting non-progressive damage to the foetal or developing brain which may affect the individual's movement and posture (Odding et al. 2006). The prevalence of children with CP is 2.11 per 1000 live births in the world (Odding et al. 2006; Oskoui et al. 2013) thus resulting in CP being the most common physical disability which affects children (Ruck et al. 2010). CP affects the child's muscle power thus impairing the child's ability to walk. Consequently, decreased muscle strength may also result in decreased Bone Mineral Density (BMD) which may lead to an increased risk in bone fractures (Ruck et al. 2010; Stark et al. 2010). Besides this, a major characteristic of CP is altered muscle tone, with spasticity being the most commonly form of altered tone present. All this lead to altered posture and movement (Sa'-Caputo et al. 2014) which also affect the child's motor function and independence. Consequently, these also cause activity and participation limitation which affect the child's quality of life (Rosenbaum et al. 2006).

There are various evidence based therapies which are used to treat children with CP (Novak et al. 2013). Strength training, constraint-induced movement therapies and casting, amongst many others are shown to be effective in the treatment of children with CP (Novak et al. 2013). A relatively new physiotherapy intervention has been introduced in order to help treat children with CP which is called Whole Body Vibration (WBV) (Stark et al. 2010). In WBV, the child is positioned either in standing, sitting or lying on a vibrating platform. The child may either stand without moving or exercises can be done dynamically whilst on the oscillating vibrating platform (Lee and Chon 2013; Sa'-Caputo et al. 2014).

WBV helps to improve walking, muscle strength, BMD, decrease tone and improve motor function (Sa'-Caputo et al. 2014) in children with CP. Therefore, WBV improves all the above mentioned outcomes using one treatment modality. Moreover, if these outcomes improve in

children with CP they also will have an improved quality of life. WBV can be used as an adjunct to other treatment modalities.

In order to improve walking, BMD, strength and function adaptive equipment and various therapy techniques are used which all cost a significant amount of money. Therefore, by improving walking, muscle strength, BMD, spasticity and motor function, cost could be greatly reduced (Hoving et al. 2007) which will relieve the burden on families and government agencies which provide funding for other therapies and equipment.

Review of the available literature about WBV is vital in order to ascertain that the effectiveness of WBV exercises actually do improve walking, muscle strength, BMD, spasticity and motor function. However, the various methodological quality of studies make analysis challenging. Therefore, in order for significant conclusions to be drawn, a detailed and complete literature review is essential to appraise and synthesise the evidence found.

# 2. BACKGROUND AND RATIONALE

# 2. BACKGROUND AND RATIONALE

A detailed background describing the pathology and clinical features of CP is given. The physiological effects of WBV are also described in detail. Apart from this, a reasoned rationale for this review is provided below.

## 2.1 BACKGROUND

### *2.1.1 PATHOLOGY AND TYPES OF CEREBRAL PALSY*

CP is an umbrella term which is defined by non-progressive damage to the developing brain (Odding et al. 2006). This damage to the brain can occur pre-, peri- and postnatally. Some examples include infections during pregnancy (chorioamnionitis) prenatally, infection due to the death of a twin or placental abruption perinatally and lack of oxygen after birth postnatally. Very low birth weight infants also have an increased risk of CP including preterm infants. There are also many cases where the aetiology is unknown (Odding et al. 2006).

The main characteristic of children with CP is motor impairment. CP can affect the child according to which limbs are affected. Hemiplegia involves one side of the body. Diplegia usually involves the two lower limbs and tetraplegia affects all four limbs. There are different types of CP including dyskinesia, ataxia and spasticity. Spasticity is the most common form of increased tone which is manifested in children with CP (Odding et al. 2006).

### *2.1.2 Clinical Features of Cerebral Palsy*

Common features found in CP include altered muscle tone, decreased muscle strength, walking difficulties, decreased BMD and decreased gross motor performance.

Spasticity is when there is an increased tendon jerk reflex and an increased sensitivity to the tonic stretch reflexes (Krause et al. 2017). This results in velocity-dependent muscle tone. Spasticity alters the posture of the child and also affects the child's movement. Decreasing spasticity will help the child to promote his/her motor development and gross motor function (Rosenbaum et al. 2007; Park et al. 2017) thus maximising the child's physical potential.

Muscle weakness co-exists with spasticity (Krause et al. 2017). Consequently, decreased muscle strength and spasticity affect the walking ability in children with CP (Scholtes et al. 2012). These factors will then affect the gross motor function of the child with CP (Rosenbaum et al. 2007). Children with CP also have a lower physical fitness when compared with children without a disability thus affecting walking (Odding et al. 2006). Goals of physiotherapy may include improving walking speed, muscle strength and gross motor function which will affect the child's participation and activities in daily life (Ketelaar et al. 2012; Saquetto et al. 2015). Therefore, therapeutic interventions which aid to facilitate the above mentioned functional outcomes should be included in physiotherapy sessions to maximise the child's potential.

Another complication of CP which results due to decreased muscle strength, tone and abnormal bone development can be decreased BMD (Ruck et al. 2010; Gusso et al. 2016). In a study by Odding et al. (2006), BMD in children was found to be lower when compared to children without a disability. Due to decreased strength mainly in the lower limbs, children with CP have less force being acted on bones during muscle contraction resulting in decreased BMD. Decreased BMD may cause low energy fractures in the lower limbs (Presedo et al. 2007).

### *2.1.3 Whole Body Vibration*

Various evidence-based therapeutic interventions may be used to target the above mentioned complications of CP. Some green-light interventions which effectively improve the outcome of CP are: bimanual training, selective dorsal rhizotomy, occupational therapy after botulinum toxin and functional training (Novak et al. 2013). A relatively new therapeutic approach is WBV (Stark et al. 2010; Sa'-Caputo et al. 2014).

WBV involves the child with CP standing, sitting or lying on a vibrating platform. The child may also perform dynamic exercises on the vibrating platform (Ruck et al. 2010; Sa'-Caputo et al. 2014; Tupimai et al. 2016). Three components of vibration therapy include frequency, amplitude and direction. Frequency is measured in Hertz (Hz), amplitude is measured in millimetres (mm) and direction is when the vibration plates either have a vertical displacement or a side-to-side displacement (Lorenzen et al. 2009; Lee and Chon 2013).

### *2.1.4 Physiological Effects of Whole Body Vibration*

In WBV, the stretch reflex is activated during muscle contraction and thus increases the motor unit activity in the targeted muscles (Delecluse et al. 2003). When a skeletal muscle senses the vibration caused by WBV, a small change in muscle length is perceived by the muscle spindles. The sensory fibres detect this change which reaches the spinal cord. By activating the sensory nerve fibres, there is a reflexive activation of motor units (Shinohara et al. 2005). The vibrations excite the muscle spindles and the alpha motor neurons, which then in turn produce a muscle contraction through the tonic vibration reflex (Cardinale et al. 2003; Sa'-Caputo et al. 2015) thus improving strength.

An aspect of spasticity is reduced inhibition of reflex activity. Vibration causes a decrease in this reflex activity by reducing the sensitivity of muscle spindle nerve endings; thus decreasing the afferent sensory input (Ritzmann et al. 2013). As a result, spasticity is decreased.

WBV can be used for strength training in the lower limbs which can improve walking in children with CP (Stark et al. 2010; Lee and Chon 2013). By improving mobility and strength, increased BMD follows due to increased muscle activation on bone during WBV using the mechanostat theory (Schoenau 2005; Gusso et al. 2015). The mechanostat theory states that muscle function affects BMD, therefore, the more muscle contractions produced by the vibrations during WBV therapy, the more BMD is increased (Schoenau 2005; Gusso et al. 2015). Apart from this, WBV appears to directly affect BMD in increasing or maintaining BMD. Mechanical stimulation produced by the vibrations from WBV, may activate the osteoblasts (cells that builds bone) and decreases the osteoclasts (cells which break down bone tissue during growth/healing) activities by increasing the circulation of fluid (El-Shamy and Mohamed 2012).

## 2.2. Rationale of the Study

A systematic review in the form of a brief report of WBV exercises for the treatment of cerebral palsy was published by Sa'-Caputo et al. in 2014. However, only a small amount of evidence was included in this brief review. A small sample size of five studies was included in this study which strongly suggests that not all literature was considered. Apart from this, more studies have been published in the meantime which further warrant a need for an update (Tupimai et al. 2016; Park et al. 2017). This can be seen when spasticity was investigated and only one article was investigated in the brief review. Furthermore, Sa'-Caputo et al. (2014) included all individuals with CP whereas another systematic review focusing on children only would be beneficial.

A more recent systematic review was carried out by Duquette et al. (2015). However, even in this review a small number of five articles were analysed with one of them focusing on adults. This systematic review included between one and four studies which analysed strength, motor function, spasticity, BMD and walking ability. Therefore, results cannot be generalised to the whole population of CP due to the low number of studies included. Moreover, having also included a study which included adults, the conclusions of the study could not be generalised to children with CP.

Another systematic review and meta-analysis was carried out by Saquetto et al. (2015) and focused on WBV in children with CP. In this study, improvement in walking ability, motor function and BMD in the femur can be concluded. However, no improvement could be seen in lumbar spine BMD and muscle strength. The lack of improvement in muscle strength differs from the results of other studies carried out, such as Lee and Chon (2013). These results are inconsistent and should, therefore, be interpreted cautiously. On the other hand, spasticity was not investigated in this study. A limitation of the study by Saquetto et al. (2015) is the small number of studies included. Therefore, a systematic review is warranted which can include more studies with more recent Randomised Controlled Trials (RCTs).

## 2.3 Conclusion

Many studies have been carried out to determine the effectiveness of WBV exercises. However, only one systematic review (Saquetto et al. 2015) was found that included children with cerebral palsy with only six studies being included. A more up-to-date systematic review would provide further in-depth research on the benefits of WBV in children with CP in the above mentioned outcomes which are further described in Chapter 3. Ultimately, this would help to inform clinical decision making and any need for future research.

# 3. AIM AND OBJECTIVES

## 3.1 AIM

The aim of this systematic review was to evaluate the state of evidence of the effectiveness of WBV exercises in children with CP.

## 3.2 OBJECTIVES

The objectives of this systematic review are described below. The effectiveness of WBV exercises were investigated in the following outcomes:

1. The effectiveness of WBV exercises in children with CP on strength.
2. The effectiveness of WBV exercises in children with CP on walking.
3. The effectiveness of WBV exercises in children with CP on function.
4. The effectiveness of WBV exercises in children with CP on BMD.
5. The effectiveness of WBV exercises in children with CP on spasticity.

## 3.3 THE PICO FRAMEWORK

The PICO framework classifies research questions to search for key words. It helps formulate the research question to be answered (Richardson et al. 1995). “P” addresses the patient population, “I” is the intervention, “C” is the comparison and “O” is the expected outcome (Table 1).

Table 1: The PICO Framework used in this study

| **Population** | **Intervention** | **Comparison** | **Outcome** |
|---|---|---|---|
| Children with cerebral palsy | Same therapy as the control/comparison plus whole body vibration exercises | The comparison/control is the same therapy as the intervention but without whole body vibration exercises | Strength<br>Walking<br>Function<br>BMD<br>Spasticity |

The PICO framework was then used to formulate the research question which is: “What is the evidence for the effectiveness of WBV for improving walking, strength, motor function, BMD and spasticity in children with CP?” This systematic review was carried out to find evidence to answer the research question.

# 4. METHODOLOGY

# 4. METHODOLOGY

In this chapter, the search strategy was described in order to answer the research question in Chapter 3. This also included the key words and the inclusion and exclusion criteria utilised. Then, the process of how the included articles were selected was described and how they were critically appraised. Finally, details about how data was extracted and analysed were also described.

## 4.1 DATABASES SEARCH

The databases below were chosen since they are most commonly used to search for reviews of health care interventions. Therefore, using these databases helped in answering the research question.

1. Cochrane Library
2. PubMed
3. CINAHL Plus with Full Text
4. MEDLINE (via EBSCOhost Research Databases)
5. PEDro

The search was conducted between 2nd and 13th May 2018.

## 4.2 KEY WORDS

The chosen key words from the research question were summarised in Table 2 so that a comprehensive search was obtained. The Boolean “AND” was used between each key term in order to retrieve articles which have all the words included and the Boolean “OR” was used to broaden the search to obtain the articles which included at least one outcome from the research question described in Chapter 3. Where possible the Medical Subject Headings (MeSH) browser was used as a thesaurus to find alternative words and to further expand the search. The Cumulative Index for Nursing and Allied Health Literature (CINAHL) headings were also used and serve the same function as the MeSH headings. These are important for the study since it includes the use of other key words to be searched which were relevant to the study. One key word only was added which was “*ambulation*”.

Table 2: The key terms used for the literature search

| | Key Words | Combination |
|---|---|---|
| **Population** | 1. Children<br>2. Cerebral palsy<br>3. Spastic diplegia<br>4. Spastic quadriplegia<br>5. Hemiplegia | 6. (2 OR 3 OR 4 OR 5) |
| **Intervention** | 7. Whole body vibration<br>8. Vibration exercise<br>9. Vibration therapy | 10. (7 OR 8 OR 9) |
| **Outcomes** | 11. Bone<br>12. Function<br>13. Motor development<br>14. Gross motor<br>15. Performance<br>16. Strength<br>17. Power<br>18. Weakness<br>19. Gait<br>20. Walking<br>21. Mobility<br>22. Ambulation<br>23. Spasticity<br>24. Hypertonia | 24. (11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24) |
| **Final Combination** | | (1 AND 6 AND 10 AND 24) |

The above key words were adapted according to the specific database used. The final combination of key words in Table 2 was used for the following databases: MEDLINE via EBSCOhost Research Databases, CINAHL Plus with Full Text, PubMed and Cochrane Library. A modified search combination was adapted for the PEDro database. The simple search was

used and the following key words were entered in the browser: “child*”, “cerebral palsy” and “vibration”. The asterisk was used so that variations of child including “children” come up. The key words, databases used, the number of hits produced and the number of abstracts selected for the systematic review were documented to provide a systematic approach to the search strategy as can be seen in Table 3.

Table 3: Template used for the documentation of the search strategy and abstracts retrieved

| **Date** | **Databases** | **Key Word Combination** | **Search limits** | **Number of hits** | **Number of duplicate articles** | **Number of abstracts selected to be reviewed for research study** | **Number of relevant studies** | **Number of selected studies** |
|---|---|---|---|---|---|---|---|---|
| | MEDLINE | | | | | | | |
| | CINAHL | | | | | | | |
| | PubMed | | | | | | | |
| | PEDro | | | | | | | |
| | Cochrane Library | | | | | | | |

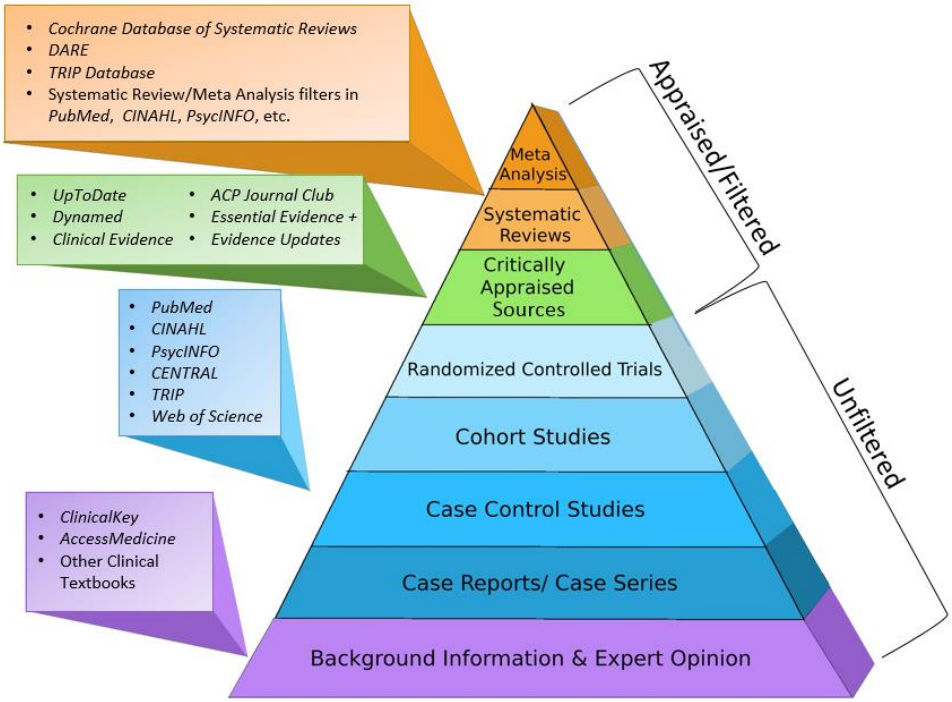
## 4.3 Inclusion and Exclusion Criteria

An inclusion and exclusion criteria to identify the relevant articles for the study was necessary in order to choose the most relevant articles. This included the study characteristics and the report characteristics which are described in further detail below.

### *4.3.1 Report characteristics*

- All Randomised Controlled Trials (RCTs) were included in this study. These types of study designs can be found at the higher end of the evidence-based medicine pyramid (Figure 1) meaning that they are considered as the best type of evidence. Other designs in the RCT family such as randomised cross-over trials were also included. The other study designs which were found at the lower end of the hierarchy level the evidence-based medicine pyramid were excluded. Articles which were excluded included case reports, opinions and case series (Figure 1) (Wisconsin University 2017).
- The articles where only the abstracts were available or were only a short poster display presentation and the full-text cannot be obtained were excluded from the study.
- The years between January 1990 and December 2018 were searched so that no relevant articles were missed.
- Articles which were in the English language were chosen.

Figure 1: The pyramid of evidence-based medicine




(Wisconsin University 2017)

### *4.3.2 STUDY CHARACTERISTICS*

*1. Population*

- Children diagnosed with CP were included in the study. According to the World Health Organisation (2013) a child is defined as an individual who is 19 years or younger. Resultantly, studies that included individuals older than 19 years old and having other neurological conditions (excluding CP) or the diagnosis is still unknown were excluded from the study. CP is described in detail in Section 2.1, and from the different types of CP, spasticity is the most common type which is manifested. With the results from this review, the effectiveness of WBV on spasticity is drawn.

- The Gross Motor Function Classification Scale (GMFCS) is a scale which focuses on the abilities of the child and classifies the different abilities of children with CP into five levels (CanChild 2018). Levels I and II are difficult to distinguish at an early age, with children in GMFCS level I being independent in walking without assistance, but have limited agility and coordination. Children with a GMFCS level II need to use the bannisters to climb up the stairs and may need a hand held walking aid/wheelchair for long distances. The distinction between GMFCS levels III, IV and V is the use of a hand held mobility device, body support walker and the use of a wheelchair and the type of wheelchair used (Palisano et al. 2008). Children with a GMFCS level III use a hand held walking aid mostly indoors and for longer distances use a wheelchair. Children with GMFCS level IV, can walk short distances with physical assistance or walk once positioned in a body support walker but otherwise use a wheelchair; whereas children at GMFCS level V need a wheelchair for both indoors and outdoors which may need adaptations since they have difficulty to maintain their head and trunk (CanChild 2018). All children with the different levels of CP were included in this study in order to understand how WBV exercises affect this motor dysfunction at the different levels.

*2. Intervention*

Details of WBV exercises and the different settings, described in Section 2.1, are summarized below.

- The inclusion criteria included studies involving WBV with children in lying, sitting or standing.
- The children may either be stationary or dynamically performing exercises on the platform.

- All parameters were included such as the amplitude and the frequency used.
- Studies which did not explain the intervention in detail including the parameters were excluded.
- Conclusively, the intervention included children with CP who utilised WBV as an adjunct to therapy.

Being a relatively new physiotherapeutic intervention, this review addresses how WBV affects children with CP and how effective it is, since Novak et al. (2013) had stated that WBV is a yellow light intervention, and should be used with caution with a sensitive outcome measure to monitor any changes.

*3. Comparator/Control*

- The comparator was the group of children with CP who did not undergo WBV exercises in the RCTs but underwent therapy only.
- In the randomised cross-over trials, there were two samples where one group, for instance, first underwent therapy with WBV (intervention) and the other group received therapy only (comparator). Then there would be a wash-out period, and in the same two samples the intervention and comparator would be reversed. Thus, each participant would serve as his/her own control. In both samples, the comparator was the participants when they did not undergo WBV exercises. Comparisons can be done within the same sample as well as between samples (Gallin and Ognibene 2012).

*4. Outcomes*

The outcomes presented in Table 1 in Chapter 3 were included in the study. These are: strength, walking, function, BMD and spasticity.

- Studies which measured other outcomes and unclear methods of the mode of measurement of the outcomes which were included in this study, were excluded.
- As previously described in Section 2.1, CP affects the motor function of the child, including strength and walking. Spasticity affects the child's movement. Resultantly, BMD is also affected. Therefore, this review addresses how WBV affects these outcomes. Common outcome measures used are described in Table 4 and in further detail below.

The Gross Motor Function Measure (GMFM) is a tool used in the clinical setting in order to measure change in gross motor function in children with CP. There are two versions, the GMFM-88 which has been validated in children with CP and children with Down's Syndrome and GMFM-66, a shorter version validated in children with CP only and gives a realistic goal setting (CanChild 2018). The GMFM is divided in five dimensions which are: (A) lying and rolling (B) sitting (C) crawling and kneeling (D) standing (E) walking, running and jumping (CanChild 2018). It has excellent reliability and validity as well as responsiveness to change (Australian Physiotherapy Association 2017). The GMFM is the gold standard to measure gross motor performance in children with CP (CanChild 2018).

The hand-held dynamometer is used to measure muscle strength. The study by Taylor et al. (2004) measured whether hand-held dynamometry was reliable in children with CP. They concluded that hand-held dynamometry is reliable to measure lower limb strength and mean changes in groups of children with CP.

In order to measure spasticity, the Modified Ashworth Scale (MAS) is the most common and practical tool used in the clinical setting. Passive muscle stretching is applied manually to the

muscle and the resistance of the muscle to this stretch is rated. This scale has a good reliability if performed by the same physiotherapist who is experienced in using this tool (Mutlu et al. 2008).

The 3-Dimensional (3D) gait analysis is the gold standard for measurement of walking. It measures movement in three planes and includes leg rotations. Markers are attached to the individual's skin and walking is tracked and measured using cameras. The data collected from gait analysis is precise and objective (Carse et al. 2013).

Dual-energy X-Ray absorptiometry is used to assess BMD in clinically important areas such as the spine and the hip. It can also help measure the effects of therapy. Apart from this, it also measures the bone and soft tissue composition of the whole body such as the legs (Laskey 1996).

Table 4: Outcomes and examples of how they will be measured

| **Outcome** | **Example measurement/Tool** |
|---|---|
| Strength | Sit-ups in 1 minute/isokinetic dynamometry |
| Walking | 6 minute walk test/3D gait analysis |
| Function | Gross Motor Function Measure (GMFM) |
| BMD | CT scan/Dual-energy X-Ray absorptiometry |
| Spasticity | Modified Ashworth Scale (MAS) |

A summary of the inclusion and exclusion criteria is found in Table 5. Any other studies which did not comply with the inclusion criteria were excluded from the study.

Table 5: A summary of the inclusion and exclusion criteria used in this study

| **Inclusion Criteria** | **Excluding Criteria** |
|---|---|
| • RCTs including cross-over trials<br>• Articles published in the English language<br>• Studies published between 1990 and May 2018<br>• Children diagnosed with CP being 19 years or younger (both males and females.<br>• Studies involving WBV where children are lying, sitting or standing on the equipment.<br>• The children may either be stationary of dynamically performing exercises on the platform.<br>• All parameters were included (e.g. amplitude, frequency).<br>• Outcomes including strength, walking, function, BMD and spasticity.<br>• How these outcomes will be measured. | • Full-text not available<br>• Articles not in the English language<br>• Study designs which are not RCTs or cross-over trials<br>• Children having other conditions excluding CP<br>• Adults with CP |

## 4.4 Study Selection

Screening by title was initially carried out. The relevant article titles were first identified from the database search of the literature carried out in section 4.2 and were categorised as being "Potentially relevant". Any duplicates were then removed. The abstracts were then read and categorised into "reject", "not sure" and "include". Then, the full-text of "not sure" and "include" were read in order to come up with the final list of articles which were included in this review. Finally, the reference lists of the included articles were also screened manually so that any more studies were identified for any additional articles which may have been missed.

## 4.5 Quality Assessment

The aim of a systematic is review is to evaluate the evidence of the effects of a health care intervention (WBV exercises) using RCTs. However, weaknesses in the conduction of the RCTs including analysis and reporting may result in false interpretation of the effectiveness of the intervention. This is called bias. Therefore, in order to minimize bias, the methodological quality of the included articles must be assessed one by one (Higgins et al. 2011).

The Cochrane Risk of Bias tool was used in this review and the risk of bias of each article was taken into consideration in the data synthesis and conclusions of the systematic review (Shamseer et al. 2015). The Cochrane Risk of Bias tool was used to ensure that the results of the effect of WBV were besides from being consistent, were not flawed. The Cochrane Risk of Bias tool is divided in six categories including: selection bias, performance bias, detection bias, attrition bias, reporting bias and other bias (The Cochrane Collaboration 2011) and it involves assessing the criteria under each category. This can be found in Appendix 1.

Ratings of “high risk of bias”, “low risk of bias” or “unclear risk of bias” were given using this tool (The Cochrane Collaboration 2011). The ratings were chosen using the criteria for judging the risk of bias using this tool (The Cochrane Collaboration 2011) and thus assess the potential bias of each article.

## 4.6 Data Extraction and analysis

Descriptive data from the retrieved articles were extracted and recorded in Tables 6-8. These included study aims, designs, sample characteristics, details of the intervention including parameters, outcome measures used, results and conclusion. The information extracted was then utilised together with the Cochrane Risk of Bias tool in order to critically analyse each study to answer the research question.

Narrative synthesis was then carried out to summarise the main findings of each included study. Therefore, firstly, data extraction is carried out to summarize each study. Then, the methodological quality of each study in turn is analysed. Data synthesis is then carried out by looking systematically at each included study as well as the relationships (similarities and differences) between the included studies (Ryan 2013).

Table 6: Template of the summary of sample characteristics

| **Study** | **Sample Size** | **Sample Age** | **Type of Cerebral Palsy** |
|---|---|---|---|
| | | | |

Table 7: Template of the summary of WBV parameters

| **Study** | **Parameters of intervention** | | | | | **Control** |
|---|---|---|---|---|---|---|
| | **Intensity (Hz and mm)** | **Details of WBV procedure used** | **Frequency (x per week)** | **Time (mins)** | **Length (week/s)** | |
| | | E.g. 3 mins of WBV, 3 mins of rest | | | | |

Table 8: Template of the summary of study design, study aims, outcome measure(s), results and conclusion of selected studies

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| | | | | | | |

# 4. RESULTS

# 5. RESULTS

The following chapter provides results of the database searches carried out and the procedure of the study selection process. Descriptive information of the results was extracted from the selected studies also providing the key findings of the selected studies.

## 5.1 ELECTRONIC DATABASE SEARCHES AND STUDY SELECTION RESULTS

The initial searches of the five databases using the final combination of key words as presented in Table 2 resulted in a total of 80 hits. A systematic breakdown of hits for each database and the final number of studies included in this systematic review are recorded in Table 9. The entire search including the study selection process can be seen in Figure 2, with the process being described in detail below.

After the initial searches which produced a total of 80 hits, all the titles were screened. The total number of relevant titles was 57, with 23 out of the 80 articles being rejected as they did not include whole body vibration therapy in children with CP. Out of the 57 potentially relevant articles retrieved, 32 articles were removed since they were duplicates resulting in 25 potentially relevant titles. The abstracts of the 25 potentially relevant titles were read and resulted in 17 potentially relevant articles. The full text of each article was read and 13 articles were excluded (Table 10). 7 articles were removed since they were not RCTs as they did not comply with the inclusion criteria (Table 5) for this study. The study by Cheng et al. (2015a) was excluded because it did not mention “randomisation” at any point in the study. The study by Mandic et al. (2012) was excluded since apart from it being a very short article it did not mention “randomisation” in its methods and no age range for the participants included in the study was given. Two studies by Yun et al. (2015) and Unger and Jelsma (2011) were removed as they

were research report poster presentations and did not meet the inclusion criteria. The study by Reyes et al. (2011) was removed as it involved children with several types of disabilities and did not exclusively include children with CP. The study by Kyvelidou et al. (2017) was dismissed since it did not use a vibrating platform but a small device and the parameters were not included. Table 10 below summarizes the exclusion of these studies.

The following twelve studies were selected: Cheng et al. (2015), El-Shamy and Mohamed (2012), El-Shamy (2014), Ibrahim et al. (2014), Katusic et al. (2013), Ko et al. (2016), Lee and Chon (2013), Ruck et al. (2010), Stark et al. (2016), Tupimai et al. (2016), Unger et al. (2017) and Wren et al. 2010. No additional studies were found after manually searching the reference lists of the included studies.

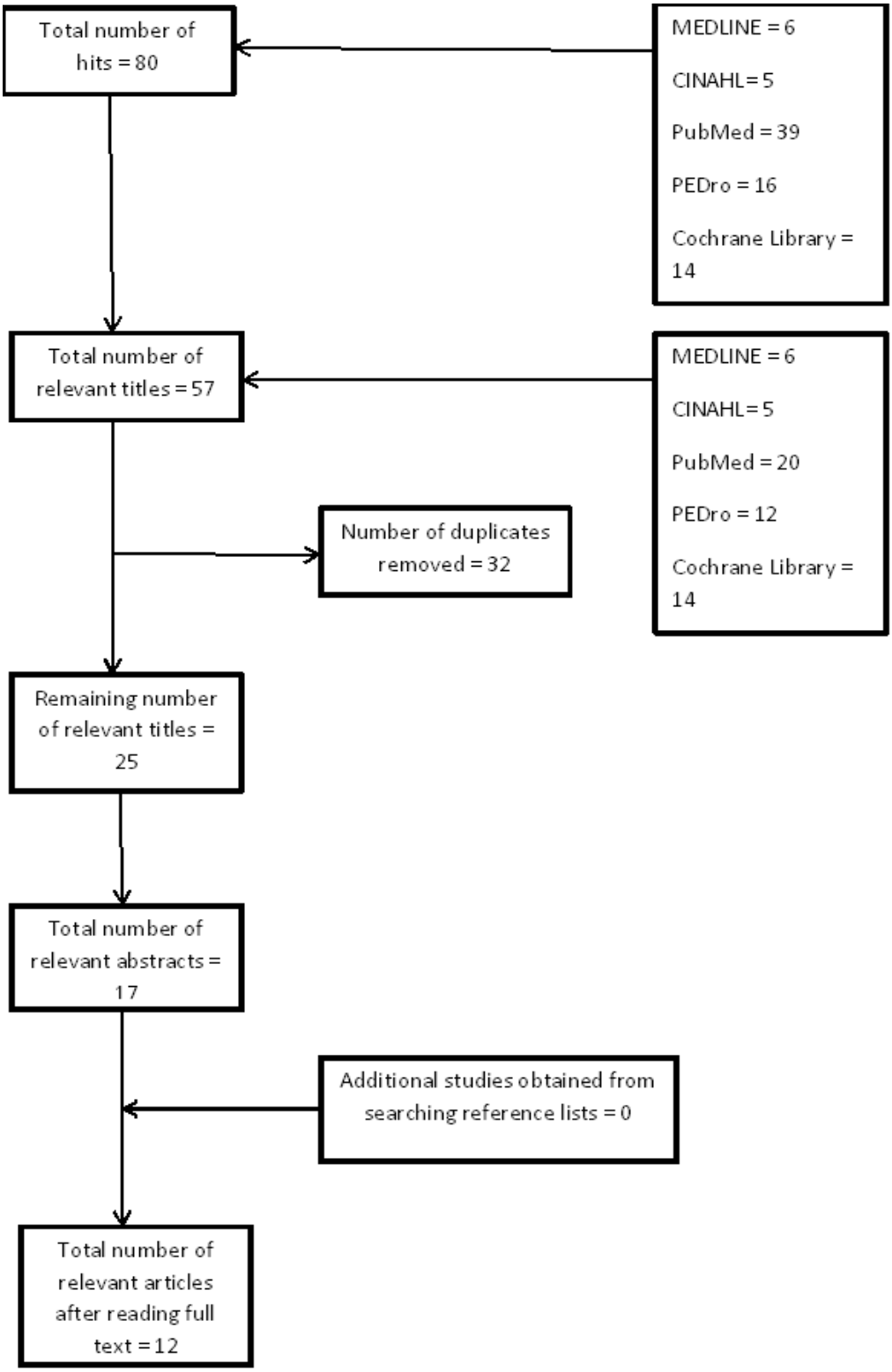
Table 9: Record of electronic searches of databases

| Date | Databases | Key Word Combination | Search limits | Number of hits | Number of duplicate articles | Number of abstracts selected to be reviewed for research study | Number of relevant studies | Number of selected studies after reading full text |
|---|---|---|---|---|---|---|---|---|
| 13/05/2018 | MEDLINE | Children AND (cerebral palsy OR spastic diplegia OR spastic quadriplegia OR hemiplegia) AND (whole body vibration OR vibration exercise OR vibration therapy) AND (bone OR function OR motor development OR gross motor OR performance OR strength OR power OR weakness OR gait OR walking OR mobility OR Ambulation OR spasticity OR hypertonia) | January 1990- May 2018<br>English language<br>All Child: 0-18 years<br>Publication Type: RCT | 6 | 32 | 25 | 17 | 12 |
| 13/05/2018 | CINAHL | | January 1990-May 2018<br>English Language<br>All child<br>RCT | 5 | | | | |
| 13/05/2018 | PubMed | | January 1990-May 2018<br>RCT | 39 | | | | |
| 13/05/2018 | Cochrane Library | | 1990-2018<br>Trials | 14 | | | | |
| 13/05/2018 | PEDro | child* cerebral palsy vibration | Not available since simple search was used | 16 | | | | |

Table 10: Studies excluded from systematic review

| Author and Year | Reason excluded from the review |
|---|---|
| Celletti and Caterota (2011) | Not an RCT |
| Cheng et al. (2015a) | No randomization is mentioned anywhere in the study |
| Katusic and Mejasli-Bosnjak (2011) | Not an RCT |
| Krause et al. (2017) | Not an RCT but a single group experimental design; no control |
| Kyvelidou et al. (2017) | No vibration platform involved with no parameters being available |
| Mandic et al. (2012) | Does not state in study that the sample chosen is randomized. No age range of participants given. Very short report |
| Park et al. (2017) | Not an RCT but a prospective intervention study; there was no control group |
| Rauch (2009) | Not an RCT |
| Reyes et al. (2011) | Children were not all diagnosed with CP |
| Semler et al. (2007) | Not an RCT |
| Stark et al. (2010) | Not an RCT but a routine procedure |
| Unger M and Jelsma (2015) | Research report poster display |
| Yun et al. (2015) | Research report poster display. Does not state if all the participants finished the study |

Figure 2: Flow chart of the entire literature search and the study selection process



## 5.2 Description of included studies

### *5.2.1 Study Designs*

Seven of the included studies were RCTs and the other five were randomised cross-over trials (Table 11) which are part of the family of RCTs.

### *5.2.2 Study Aims*

All the included studies clearly stated their aims of the effects of WBV in children with CP. Three of the included studies investigated the effects of WBV training in spasticity (Ibrahim et al. 2014; Cheng et al. 2015; Tupimai et al. 2016). Six studies aimed to investigate how WBV affects walking (Ruck et al. 2010; Lee and Chon 2013; Ibrahim et al. 2014; Cheng et al. 2015; Ko et al. 2016; Unger et al. 2017). In Unger et al.'s (2017) study, the authors investigated if strengthening the trunk muscles via WBV will affect gait and posture. However, posture was not an outcome that was included in this systematic review. Three studies aimed to evaluate the effectiveness of WBV on BMD (Ruck et al. 2010; Wren et al. 2010; El-Shamy and Mohammed 2012). Another outcome investigated in this review was motor function. Four studies aimed to investigate this outcome (Ruck et al. 2010; Ibrahim et al. 2014; Katusic et al. 2014; Stark et al. 2016). The most common outcome investigated, together with walking, was muscle strength. Six of the included studies aimed to investigate the effectiveness of WBV on muscle strength (Wren et al. 2010; Lee and Chon 2013; El-Shamy 2014; Ibrahim et al. 2014; Tupimai et al. 2016; Unger et al. 2017;). Some of the above mentioned studies measured other outcomes which were not included in this review such as joint-position and balance. A summary of the study aims extracted from the mentioned studies can be found in Table 11.

Table 11: Summary for the data extraction of the study designs, study aims, outcome measure(s), results and conclusion of selected studies

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Cheng et al. 2015 | Cross-over design<br><br>4 weeks washout period | To evaluate the effect of an 8-week WBV on lower extremity spasticity and ambulatory function in children with CP | - Measurement of joint range AROM and PROM using electrogoniometers.<br>- Wartenburg Pendulum test to measure spasticity<br>- MAS to measure spasticity<br>- TUG test to measure walking balance<br>- 6 minute walk test measures the walking ability (functional measurement) | - Variable measured before the treatment (Time1; baseline)<br>- After 8-week treatment (Time2)<br>- 1 day after (Time3) 8-week treatment<br>- 3 days after (Time4) 8-week treatment | - Significant differences were found in change scores between the WBV and control for MAS, Relaxation Index (RI) and 6 minute walk test.<br>- Effects last up to 3 days after the WBV intervention<br>- No significant difference in change score between WBV and control groups in TUG tests | Spasticity is controlled by WBV, it also improves walking in children with CP. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| El-Shamy and Mohamed 2012 | RCT | To evaluate the effects of WBV therapy on BMD after 6 months | - Dual-energy X-ray absorptiometry | - Baseline<br>- After 6 months | - Insignificant difference was found in BMD in both WBV and control groups in the femur pre-treatment<br>- There was a significant difference between the results of BMD in the femur pre- and post-treatment in the WBV group.<br>- In both WBV and control groups in the lumbar spine there was an insignificant difference in BMD pre-treatment. Significant difference between both groups post-treatment in favour of the WBV group in the lumbar spine<br>- Insignificant difference in BMD in both WBV and control groups in total body pre-treatment.<br>- There was a significant difference in results between the groups at baseline after 6 months. | WBV improves BMD in children with CP |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| El-Shamy 2014 | RCT | To investigate the effects of WBV training on muscle strength and balance in children with diplegic CP | - Biodex isokinetic dynamometer to measure knee extensor strength<br>- Biodex Balance System to measure balance | - Baseline<br>- Post-treatment assessments after 3 months | - Before treatment was carried out there was no significant difference in the strength between the control and the WBV group<br>- There was a statistically significant difference between the mean values of the quadriceps strength obtained during baseline and post-treatment assessments.<br>- Children in the WBV group showed a remarkable improvement when compared with the children in the control group. | WBV may be useful to increase muscle strength and balance in children with diplegia. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Ibrahim et al. 2014 | RCT | To evaluate the effect of WBV training on muscle strength, spasticity and motor performance in children with spastic diplegia CP | - A dynamometer was used to measure the isometric strength of knee extensors<br>- MAS was used to measure spasticity of hip adductors, knee extensors and ankle plantar flexors<br>- 6 minute walk test was used to measure walking speed<br>- TUG test was used to measure walking balance and mobility<br>- GMFM-88 was used to measure gross motor performance | - Baseline (before the treatment period)<br>- After 12 weeks treatment | - Significant increase in the knee extensors comparing the pre- and post- treatment results of both weak and strong legs in the WBV group while there was no significant change in the control group.<br>- There was a significant reduction of spasticity in the knee extensors of the stronger leg in the WBV group and no significant change in the control group after the treatment<br>- The values for both groups in dimension D of the GMFM were significantly increased after the intervention. The total value for dimension E were significantly increased in the WBV group whereas no significant change was found in the control group.<br>-No significant changes in TUG results in either group nor between groups | WBV can improve muscle strength, walking speed and gross motor function related to standing and walking in children with CP. It may also decrease spasticity whereas walking balance had no significant difference. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Katusic et al. 2013 | RCT | The effects of WBV on spasticity and motor function were evaluated. | - Modified Modified Ashworth Scale (MMAS)<br>- GMFM-88 | - Baseline<br>- 12 weeks post-treatment | - Significant decrease in spasticity was found in both groups. There is a significant change in scores on the MMAS between the groups in favour of the WBV group<br>- GMFM scores improved in both groups. There was a significant difference in change between the scores between both groups post-treatment in favour of the WBV group.<br>- No significant difference in effects for GMFM and MMAS in children classified GMFCS levels V and IV and levels III and II | It was concluded that vibration therapy decreases spasticity and improves motor function especially in children with CP. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Ko et al. 2016 | RCT | To observe the effects of WBV together with traditional physiotherapy compared with traditional physiotherapy on proprioception, balance and walking in children with CP | - A Tilt-meter was used to measure proprioception<br>- Tetrax Interactive Balance System to measure balance<br>- OptoGait System to measure gait two-dimensionally | - Baseline (pre-treatment)<br>- 3 weeks after baseline (post-treatment) | - No significant difference was found in proprioception except in the ankle in the WBV group<br>- No significant difference was noted in balance<br>- No statistically significant difference between control group and WBV groups in gait. Significant difference in gait speed, step length and step width were found in the WBV group. | Improved proprioception in the ankle and gait speed, step length and step width was noted after three weeks of WBV therapy in children with CP |
| Lee and Chon 2013 | RCT | Ambulatory function and leg muscle thickness after WBV in children with CP | - Three-dimensional gait analysis<br>- Ultrasonographic imaging of the the leg muscles<br>- GMFM | - Baseline<br>- After the 8 week post-treatment | - Significant improvement in the WBV group in walking speed, step length and cycle time when compared to the control group.<br>- Significant difference in the ankle angle in the WBV group when compared to the WBV group.<br>- Significant thickness in the Tibialis anterior and soleus muscles but no significant difference in the gastrocnemius in the WBV group. | WBV improves mobility in children with CP by improving gait speed, increase muscle strength |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Ruck et al. 2010 | Randomised controlled pilot study | To investigate the effectiveness of WBV therapy in children with CP | - GMFM-88<br>- 10m walk test<br>- Dual-energy X-Ray absorptiometry measures bone densitometry | - Baseline<br>- After the 6-month treatment | - No significant differences in the changes in the scores for the GMFM were obtained between the two groups<br>- Significant difference was obtained in the 10m walking speed test in the WBV group with no change in the control group<br>- There was a significant difference in distal femoral diaphysis (Region 3) with a decrease in BMD in the WBV group<br>- When it comes to lumbar spine and distal femur (Region 1 and 2), no significant difference was noted. | WBV therapy improves walking function in children with CP. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Stark et al. 2016 | RCT - prospective, evaluator-blinded, mono-center, randomized waiting-control design with follow-up (cross-over trial) | To investigate feasibility and effectiveness of home-based side-alternating WBV (sWBV) therapy in order to improve motor function in young children | - GMFM-66 to measure motor function<br>- Paediatric Evaluation of Disability Inventory (PEDI) | - Baseline (T0)<br>- 14 weeks (T1)<br>- 28 weeks (T2) | - Both groups improved in GMFM-66 scores. No significant difference was found between the groups. | A 14-week home-based sWBV intervention was feasible and safe in toddlers with CP, however it was not associated with improvement in gross motor function. |
| Tupimai et al. 2016 | Randomized two-period cross-over trial | To evaluate the immediate and short-term effects of prolonged muscle stretching (PMS) and WBV (on tilting table) on the spasticity, strength and balance of children and adolescents with CP | - MAS to measure spasticity<br>- Time one can perform five times sit to stands to measure lower limb muscle strength | - After one treatment session<br>- After 6 weeks treatment for immediate effects. | - After 6 weeks combined PMS and WBV had beneficial effects on spasticity and muscle strength compared to the control group which included PMS only<br>- Significantly decreased scores on the Modified Ashworth Scale in the WBV group<br>- Both control group and WBV group showed significantly reduced the performance times in the five times sit to stand test | Combined PMS and WBV have beneficial effects in improving spasticity and muscle strength in children with CP |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Unger et al. 2017 | cross-over | To determine whether strengthening trunk muscles using vibration can improve posture and gait in children with spastic -type CP | - 1-minute walk test to measure walking<br>- 2D-posturography<br>- US imaging to measure resting abdominal muscle thickness<br>- Total number of sit-ups in one minute to measure abdominal strength | - Baseline (M1)<br>- 4 weeks (M2)<br>- 8 weeks (M3) | - Significant difference in gait speed following WBV in Groups 1 and 2<br>- No significant difference between M1 and M3 in Group 1 which indicates that the treatment effect was not sustained after the intervention was withdrawn<br>-Significant improvement in performing sit-ups in one minute. Results for Group 1 at M2 indicated that the WBV effect was sustained after the intervention was withdrawn.<br>-Abdominal muscle thickness improved significantly post WBV. The effect remained for the RA and OE muscles while the TrA and OI returned to baseline measurements after WBV was stopped (despite the ability to execute repeated sit-ups in one minute.) | In the short term, WBV exercises, significantly improve posture and self-selected fast walking. However, these were not maintained in the long term following withdrawal of the WBV intervention.<br><br>The maintained ability to execute sit-ups and the increase recorded in selected resting abdominal muscle thickness confirm the gain in functional abdominal muscle strength. |

| Study | Study design | Study Aims | Outcome Measures | Data Collection Points | Results | Conclusion |
|---|---|---|---|---|---|---|
| Wren et al 2010 | Prospective randomized cross-over | To investigate the effects of WBV on bone and muscle in children with CP | CT measurements of bone and muscle (General Electric LightSpeed QX/i)<br><br>Strength was measured using a dynamometer | 0 months<br>6 months<br>12 months | - Significant difference was increased cortical bone during the vibration period (in the tibial diaphysis)<br>- No significant change in muscle area<br>- No significant difference for the strength outcome | Increased bone area in the tibial diaphysis<br>No increase in muscle area or strength found |

CP – cerebral palsy, AROM – active range of motion, PROM – passive range of motion, TUG – timed up and go test, RCT – randomised controlled trial, WBV – whole body vibration, BMD – bone mineral density, MAS – Modified Ashworth Scale, GMFM-88 – Gross Motor Function Measure–88, MMAS – Modified Modified Ashworth Scale, GMFCS – Gross Motor Function Classification Scale

### *5.2.3 Sample Recruitment*

The authors recruited participants for their studies from various settings with the most common being special education schools. Five studies recruited participants from special schools (Ruck et al. 2010; Lee and Chon 2013; Cheng et al. 2015; Tupimai et al. 2016; Unger et al. 2017). One study recruited participants from both a special education school and a local hospital (Cheng et al. 2015). The study by Stark et al. (2016) also recruited participants from a local hospital. Three studies recruited participants from an Outpatient clinic (El-Shamy and Mohamed 2012; El-Shamy 2014; Ibrahim et al. 2014) and one study from a day-care centre (Katusic et al. 2013). Studies that were conducted by Ko et al. (2016) and Wren et al. (2010) did not address their participants' recruitment.

### *5.2.4 Sample Characteristics*

In the following section the inclusion and exclusion criteria of the sample population are included together with the description of the sample populations in the included studies. The sample size and sample gender are also included. A summary of the sample population is described in Table 12. The ethical aspects were also considered.

#### 5.2.4.1 Inclusion and exclusion criteria

All studies included children aged between 1 and 18 years. All children had a diagnosis of CP except one study (Stark et al. 2016) which stated that the children either had CP or were highly suspected to have CP from a neurologist. The most common age range in all the studies was 6-13 years with only one study including children between 1-2 years (Stark et al. 2016) and one including 6-18 years (Tupimai et al. 2016). Children with GMFCS levels I-III were included in

most studies with two studies (Ruck et al. 2010; Stark et al. 2016) including children with GMFCS levels II-IV. Only one study (Katusic et al. 2013) included children with GMFCS levels II-V. One study by Lee and Chon (2013) included only children with CP who could walk independently without a walking aid. Seven studies required children with CP to be able to walk with or without a walking aid and comprehend and follow instructions in order to be included in the study (Wren et al. 2010; El-Shamy and Mohamed 2012; El-Shamy 2014; Ibrahim et al. 2014; Cheng et al. 2015; Ko et al. 2016; Unger et al. 2017).

In most of the studies, the exclusion criteria included: no surgery in the past 6 months, no botulinum toxin in the past 3/6 months, uncontrolled seizures, severe medical conditions, fractures, acute inflammation of the musculoskeletal system and any change in medication which alters tone. In the study by Wren et al. (2010), the authors excluded children who had a high bone density since BMD was the primary objective of this study.

#### 5.2.4.2 Sample Size

The total number of participants across the twelve studies being children diagnosed with CP was 363. The sample size ranged from 12 (Tupimai et al. 2016) to 89 (Katusic et al. 2013) participants. The mean sample size per study was 30.25.

#### 5.2.4.3 Sample Sex

The children in the studies included both males and females. Two studies had an equal number of boys and girls in their sample (Lee and Chon 2013; Cheng et al. 2015). Three studies had more boys than girls in their samples (Ruck et al. 2010; El-Shamy and Mohamed 2012; Katusic et al. 2013). Only one study had more girls than boys (Ko et al. 2016). The other studies did not mention how many boys and girls participated in their studies.

Table 12: Summary of sample characteristics

| Study | Sample Size (n) | Sample Sex | Sample Age (years) | Type of Cerebral Palsy |
|---|---|---|---|---|
| Cheng et al. 2015 | 16 | 8 boys<br>8 girls | 9.2 | Spastic diplegia (n=11)<br>Spastic quadriplegia (n=5)<br><br>Most walked independently without aids<br><br>Four used 4-wheeled walkers for walking |
| El-Shamy and Mohamed 2012 | 30 | 17 boys<br>13 girls | 10-13 | Spastic diplegia |
| El-Shamy 2014 | 30 | | 8-12 | Spastic diplegia |
| Ibrahim et al. 2014 | 30 | | 8-12 | Spastic diplegia |
| Katusic et al. 2013 | 89 | 52 boys<br>37 girls | 4-6 | Uni/bilateral spastic CP (includes hemiplegia/diplegia/quadriplegia)<br><br>15 uni<br>74 bilateral<br><br>GMFCS Level<br>Level 2= 8<br>Level 3 = 11<br>Level 4 = 7<br>Level 5 = 63 |

| Study | Sample Size (n) | Sample Sex | Sample Age (years) | Type of Cerebral Palsy |
|---|---|---|---|---|
| Ko et al. 2016 | 24 | 10 boys<br>14 girls | 7-13 | Diplegia = 14<br>Hemiplegia = 10<br><br>GMFCS Level<br>Level 1 = 13<br>Level 2 = 6<br>Level 3 = 5 |
| Lee and Chon 2013 | 30 | 15 males<br>15 females | 10 (2.26 - mean standard deviation)<br>9.66 (2.58- mean standard deviation) | Spastic diplegia or quadriplegia |
| Ruck et al. 2010 | 20 | 14 boys<br>6 girls | 6.2-12.3 | GMFCS<br>Levels II, III, IV |
| Stark et al. 2016 | 24 | | 1-2 (corrected age) | GMFCS Levels II, III,IV |
| Tupimai et al. 2016 | 12 | | 6-18 | Spastic CP<br><br>GMFCS<br>Level I<br>Level II<br>Level III |
| Unger et al. 2017 | 27 | | 6-13 | Spastic CP: diplegia and hemiplegia<br><br>GMFCS<br>Level I<br>Level II<br>Level III |
| Wren et al. 2010 | 31 | | 6-12 | |

### *5.2.5. ETHICS APPROVAL AND CONSENT*

Ten out of twelve studies had their study approved from their respective boards and written informed consent from the families/legal guardians/participants obtained. The study by El-Shamy and Mohamed (2012) did not specify whether the study was approved and the study by Ko et al. (2016) did not mention that written informed consent was obtained from the families/legal guardians/participants.

## 5.3 INTERVENTIONS

In the section below, the interventions of WBV and the control are described. Details of the protocols utilized in WBV, the duration of intervention and sessions, the frequency of intervention, the parameters used and the control were described. A detailed summary of the interventions and control treatments is presented in Table 13.

Table 13: Summary of the intervention, control and procedure/protocol used

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| | | | E.g. 3 mins of WBV, 3 mins of rest | | | | |
| Cheng et al. 2015 | AV-001A, Body Green, Tapei, Taiwan | 20Hz<br><br>Vertical displacement of 2mm | 10 mins of vibration<br><br>Participant externally strapped for support with knees 30 degrees flexed.<br><br>Patient stationary on platform | 3 | 10 | 8 weeks | Same procedure but the vibration machine was not turned on (8 weeks long) |
| El-Shamy and Mohamed 2012 | ? | 0.3 *g*<br>25Hz<br>1.7mm (amplitude) | Physical therapy programme plus WBV<br><br>5 mins warming up<br>10 mins WBV (rest included) and performed in a static standing position with the knees bent | 5 | 10 | 6 months | Physical therapy programme: 1 hr, 5 times weekly for 6 months |

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| El-Shamy 2014 | Vibraflex Home Edition II WBV device (Orthometric Inc., While Plains, NY) a.k.a. Galileo Basic | Increasing gradually 12Hz to 18Hz<br><br>Increasing 2mm to 4mm<br><br>Side-to-side alternating vertical sinusoidal vibration | Traditional physiotherapy programme plus WBV<br><br>3 mins WBV<br>3 mins of rest<br>3mins of WBV<br>3 mins of rest<br>3mins of WBV<br><br>Performed in a standing position with knees and hips flexed | 5 | 9 | 3 months | Traditional physical therapy exercise programme for 3 successive months |
| Ibrahim et al. 2014 | Power Plate (Northbrook, IL) | Ranged from 12-18Hz<br><br>4-6mm<br><br>Side-alternating vibration platform | Physiotherapy treatment programme plus WBV<br><br>3 mins WBV<br>3 mins of rest<br>3mins of WBV<br>3 mins of rest<br>3mins of WBV<br><br>Standing with shoes on and knees slightly bent | | 9 | 3 months | Physiotherapy treatment programme: 1 hr, three times a week for 3 months |

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| Katusic et al. 2013 | Vibroacoustic bedpad (VISIC bedpad-VSM 10, Acouve Laboratory Inc. Japan) | 40Hz<br><br>Amplitude variations, 6.8 seconds between peaks | Physiotherapy treatment plus WBV<br><br>20mins WBV treatment session<br><br>Supine with head in midline; some children need pillows | 2 | 20 | 3 months | Physiotherapy treatment: 3 sessions of 40 minutes per week |
| Ko et al. 2016 | Galileo System (Novotec Medical, Pforzheim, Germany) | 20-24Hz<br>1-2mm (amplitude)<br><br>Side-to-side vertical sinusoidal vibrations | Traditional physiotherapy plus WBV<br><br>3 mins WBV<br>3 mins rest<br>3 mins WBV<br>3 mins rest<br>3 mins WBV<br><br>Standing with bare feet with knees flexed 30 degrees | 2 | 9 mins | 3 weeks | Traditional physiotherapy: 30 mins, twice weekly for 3 weeks |

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| Lee and Chon 2013 | Galileo System (Novatec Medical GmbH, Pforzheim, Germany) | 5-25 Hz<br>1-9mm | Traditional physiotherapy plus WBV<br><br>3 mins of 5–8 Hz<br>3 min rest<br>3 mins of 10–15 Hz<br>3 mins rest<br>3 mins of 15–20 Hz<br>3 mins rest<br>3 mins 20–25 Hz<br>3 mins rest<br>3 mins of 15–20 Hz<br>3 mins rest<br>3 mins of 10–15 Hz.<br>Additionally, a 10- minute warm up and another 10-minute cool-down (passive range of motion exercises) were included before and after the WBV programme (total duration approx. 1 hour).<br>Squatting 30 to 100 degrees of knee flexion on the vibrating platform<br>Barefoot | 3 | 18 | 8 weeks | Traditional physiotherapy: 3 days a week for 8 weeks |

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| Ruck et al. 2010 | Vibraflex Home Edition II (Orthometric Inc, White Plains, NY) a.k.a. Galileo Basic | 12 Hz - 18 Hz<br><br>4mm | Physiotherapy programme plus WBV<br><br>3 mins of WBV<br>3 mins rest<br>3 mins of WBV<br>3 mins rest<br>3 mins of WBV<br><br>Standing with knees and hips bent between 10 and 45 degrees | 5 | 9 | 6 months | Physiotherapy programme: one to two sessions per week |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Stark et al. 2016 | Galileo system with a tilt table (Novotec. Medical GmbH, Pforzheim, Germany) | 12 or 22 Hz alternately between exercises<br><br>2.5mm<br><br>Side alternating WBV | Standard care including physiotherapy plus WBV<br><br>3 times for 3 mins:<br>-Standing still or alternately squatting and standing up<br>-Sitting on the platform<br>-4 point position<br><br>(Training involves 10 times per week. Either 2x per day during the week, or once per day during the week and twice on weekend days)<br><br>The tilt table ranges from supine (0 degrees) to upright (90 degrees) and standing with knees bent barefoot/shoes/orthotics | 10 | 9 | 14 weeks | Standard care including physiotherapy |

| Study | Parameters of intervention | | | | | | Control |
|---|---|---|---|---|---|---|---|
| | Name of WBV equipment | Intensity (Hz and mm) | Details of WBV procedure used | Frequency (x per week) | Time (mins) | Length | |
| Tupimai et al. 2016 | AIKO vibrator, ETF-001CG (Thailand) | 20 Hz<br><br>Amplitude becomes larger; but no details of amplitude given | Passive muscle stretching plus WBV<br><br>30 mins passive muscle stretching prior to WBV<br><br>1 min vibration<br>1 min rest<br>(This WBV procedure is repeated) till a total of 10 mins WBV is obtained | 5 | 10 | 6 weeks | Passive muscle stretching (while standing on a tilt-table for 40 mins 5 times per week) |
| Unger et al. 2017 | Not mentioned | 35-40Hz<br><br>Amplitude not mentioned | Trunk targeted exercise programme plus WBV | Protocol twice in week 1,<br>Three times in week 2,<br>4-5 times in weeks 3 and 4. | 30-45-60 seconds per exercise | 8 weeks | Trunk targeted exercise programme |
| Wren et al. 2010 | Juvent Medical Inc. Somerset, NJ | 30 Hz | Standing on a vibrating platform for 10 mins<br><br>Can use AFOs | daily | 10 mins | 6 months | Standing for 10 mins daily for 6 months |

Hz – Hertz, Mm – millimetres, x – times, mins - minutes

### *5.3.1. WBV Protocol/Procedure*

Though WBV training was used in all the studies, different protocols were used. Four studies out of twelve used the same protocol for their participants (Ruck et al. 2010; El-Shamy 2014; Ibrahim et al. 2016; Ko et al. 2016). This involved 3 minutes of WBV and 3 minutes rest for three times while the subject was externally strapped in a standing position with the knees flexed plus their physiotherapy programme. Another two studies used the same protocol which included standing on a vibrating platform for 10 minutes (Wren et al. 2010; Cheng et al. 2015). The other six studies utilized different protocols which are described in Table 13.

### *5.3.2 Duration of interventions and sessions*

The duration of the interventions ranged from the shortest intervention of 3 weeks (Ko et al. 2016) to the longest intervention of 6 months (Ruck et al. 2010; Wren et al. 2010; El-Shamy and Mohamed 2012). All the intervention sessions took approximately between 9 and 20 minutes of WBV (Table 13).

### *5.3.3. Frequency of interventions*

The frequency of interventions was different in some of the studies, being two, three or five times per week and daily. Table 13 presents a summary of the frequency of interventions in the twelve studies.

### *5.3.4 Intervention parameters*

Different WBV brands were used and are described in Table 13. The frequency of the WBV ranged from 5-40 Hz with the most common ranges being between 12-18 Hz (Ruck et al. 2010; El-Shamy 2014; Ibrahim et al. 2016). The amplitude ranged from 1-9 mm with eight of the studies presenting with different ranges of amplitude. The four of the other studies did not mention the exact value range for the amplitude or left it out (Wren et al. 2010; Katusic et al. 2013; Tupimai et al. 2016; Unger et al. 2017).

## 5.4 Control intervention/comparison

The WBV group all received the same therapy as the control plus the WBV training. Seven studies included traditional physiotherapy as the control group (Ruck et al. 2010; Katusic et al. 2013; Lee and Chon 2013; El-Shamy 2014; Ibrahim et al. 2014; Ko et al. 2016; Stark et al. 2016). The comparison for two studies was standing only, either on the floor or on the platform which was switched off (Wren et al. 2010; Cheng et al. 2015). In the study by Cheng et al. (2015), both groups continued their usual daily routine during the treatment. One study had a physiotherapy programme of five times a week as a control (El-Shamy and Mohamed 2012), another had prolonged muscle stretching while on a WBV platform which was switched off (Tupimai et al. 2016) and Unger et al.'s (2017) study had a trunk targeted programme.

## 5.5 Types of Outcome Measures

The different types of outcomes measured in this systematic review were: muscle strength, walking, motor function, BMD and spasticity. A summary of the outcome measures can be found in Table 11.

### *5.5.1 STRENGTH*

The dynamometer was the most common tool used to measure strength (Wren et al. 2010; Ibrahim et al. 2014; El-Shamy 2014). Lower limb strength was also measured by the time an individual can perform sit to stands for five times (Tupimai 2016). Unger et al.'s study (2017) used the total number of sit-ups in one minute as an outcome measure though this test is not a standardized one. However, this outcome measure is used in various research studies to investigate the possible increase in abdominal muscle strength (Moreland et al. 1997). Ultrasonographic imaging was used to measure leg muscle thickness (Lee and Chon 2013) and abdominal thickness (Unger et al. 2017) pre- and post- treatment. To measure muscle thickness of the calf muscle, Wren et al. (2010) used CT measurements.

### *5.5.2 WALKING*

Six studies measured walking in children with CP after WBV treatment. Two studies (Ibrahim et al. 2014; Cheng et al. 2015) used the 6 minute walk test whereas one study (Unger et al. 2017) used the 1 minute walk test. The 6 minute walk test measures the distance walked by the participant in 6 minutes whereas the 1 minute walk test measures the distance walked in 1 minute. One study (Ruck et al. 2010) used the 10 metre walking test to measure walking speed and two other studies (Lee and Chon 2013; Ko et al. 2016) used a 2-dimensional/3-dimensional gait analysis.

Two studies (Ibrahim et al. 2014; Cheng et al.2015) measured walking using the Timed Up and Go (TUG) test. The TUG test is a quick outcome measure commonly used in the clinical setting to measure mobility (Dhote et al. 2012).

### *5.5.3 Function*

The motor function was measured in four studies (Ruck et al. 2010; Katusic et al. 2013; Ibrahim et al. 2014; Stark et al. 2016). The GMFM was used to measure motor performance in all of the studies and this is described in detail in Chapter 4. The reliability and validity of the GMFM has been tested to be good in children with CP (Bjornson et al. 1998).

### *5.5.4 Bone Mineral Density (BMD)*

Two studies (Ruck et al. 2010; El-Shamy and Mohamed 2012;) used dual energy X-Ray absorptionometry while one study (Wren et al. 2010) used CT measurements (CT-T bone densitometry) to measure BMD.

### *5.5.5 Spasticity*

Three studies (Ibrahim et al. 2014; Cheng et al. 2015; Tupimai et al. 2016;) used the MAS to measure spasticity. The MAS is described in further detail in Chapter 4. In Katusic et al.'s (2013) study the Modified Modified Ashworth Scale (MMAS) was used. This is different than the MAS since the MAS has 6 options to score for spasticity while the MMAS has 5 options.

### *5.5.6 Additional Outcome Measures*

Other outcomes which were not of interest for this systematic review were measured but their results were not discussed. These included three studies which measured balance (El-Shamy 2014; Ko et al. 2016; Tupimai et al. 2016), one study by Ko et al. (2016) which measured proprioception and one study by Unger et al. (2017) which measured posture. In El-Shamy's

(2014) study he used the Biodex Balance System to measure balance. In Ko et al.'s (2016) study they used a tilt-meter to measure proprioception and the Tetrax Interactive Balance System to measure balance. To measure balance Tupimai et al. (2016) used the Paediatric Balance Scale. Finally, Unger et al. (2017) used the digital photographic 2-D postural analysis to measure posture.

## 5.6 Quality Assessment of Selected Studies

The Cochrane Collaboration Risk of Bias Tool was used to assess the methodological quality of the twelve studies selected for this systematic review. A summary of the results is presented in Table 14. There are various domains and these can be rated with "high", "low" or "unclear" risk of bias which are supported either using the reviewer's judgment or using evidence from the studies. Appendix 2 includes the detailed risk of bias assessment carried out for each study selected in this systematic review.

In the domain of "performance bias", the reviewer chose to rate it as "unclear" risk of bias in the majority of the studies. Blinding of participants and personnel is very difficult since the WBV equipment is easily observable and participants would notice it in their intervention group. Apart from this, the vibration can also be felt by the participants. Two studies by Cheng et al. (2015) and Tupimai et al. (2016) attempted to blind participants while the control group stood on a vibrating platform which was switched off. However, still the personnel operating the equipment would know whether it was switched on or not. Ideally those applying the WBV system would not be involved in the study so that risk of bias of authors knowing which group the children were in would be absent. Most of the studies did not specifically mention this in their studies though five studies mentioned that physiotherapists who were not the investigator carried out the WBV training (Ruck et al. 2010; El-Shamy and Mohamed 2012; Stark et al. 2016; Lee and

Chon 2013; Unger et al. 2017). However, the author still did not state specifically that they were "blinded" to the groups.

The sample size was another factor which may influence the generalizability of the results. The majority of the studies had between 12 - 30 people, thus making it difficult to generalize to the whole population of children with CP. Apart from this, some studies carried random stratified sampling so that different levels were in different intervention and control groups. However, having already a small sample size, few children with the same level will be in each group resulting in further difficulty to generalize results. Only one study by Katusic et al. (2013) included children with level V of the GMFCS with it being the only study having over thirty participants.

Table 14 – Risk of bias assessment results

| Author (Year) | Selection Bias | | Performance Bias (blinding of participants and personnel) | Detection Bias (blinding of outcome assessment | Attrition Bias (incomplete outcome data) | Reporting Bias (selective reporting) | Other Bias |
|---|---|---|---|---|---|---|---|
| | Random sequence generation | Allocation concealment | | | | | |
| Cheng et al. (2015) | Unclear | Unclear | Unclear | Unclear | Low | Low | |
| El-Shamy and Mohamed (2012) | Low | Unclear | Unclear | Unclear | Unclear | Low | High |
| El-Shamy (2014) | Low | Low | Unclear | Low | Low | Low | Unclear |
| Ibrahim et al. (2014) | Unclear | Unclear | Unclear | Unclear | Low | Low | Low |
| Katusic et al. (2013) | Low | Unclear | Low | Low | Low | Low | |
| Ko et al. (2016) | Unclear | Unclear | Unclear | High | Low | Low | |
| Lee and Chon (2013) | Unclear | Low | Unclear | Low | Low | Low | Unclear |
| Ruck et al. (2010) | Unclear | Low | Unclear | High | Low | Low | |
| Stark et al. (2016) | Low | Low | Unclear | Low | Low | Low | Unclear |
| Tupimai et al. (2016) | Low | Unclear | High | Unclear | Low | High | Unclear |
| Unger et al. (2017) | Low | Unclear | Unclear | Low | Unclear | Low | Unclear |
| Wren et al. (2010) | Low | Low | Unclear | Unclear | Low | Low | |

Low= low risk of bias, High= high risk of bias, Unclear= Unclear risk of bias

## 5.7 Study Results

### *5.7.1 Strength*

Three studies resulted in a significant increase in muscle strength. In the study by Ibrahim et al. (2014), there was a significant increase in the knee extensors of both lower limbs (weak and strong legs with p = 0.009 and p = 0.013 respectively) in the WBV group only. There was also only a significant difference post-treatment in the WBV group in the weak leg (p = 0.028) and not in the strong leg (p = 0.61). A significant increase (p = 0.001) in muscle strength in the knee extensors in the WBV group was found in the study by El-Shamy (2014) as well a significant difference was found between the WBV and control groups in favour of the WBV group. In another study by Unger et al. (2017) participants in the WBV group had an increase in abdominal strength with a statistically significant interaction (p<0.001) in the ability to perform more sit-ups in one minute. In the study by Tupimai et al. (2016), there was no significant difference (p > 0.05) between the groups in strength. No significant difference was found in muscle thickness in the gastrocnemius/calf area in two studies after WBV treatment (Wren et al. 2010; Lee and Chon 2013) with p values of 0.0645 and p > 0.10 respectively. However, significant increase was found in the Tibialis anterior (p = 0.001) and soleus muscle (p = 0.001) after WBV (Lee and Chon 2013) and in abdominal muscle thickness (p < 0.05) (Unger et al. 2017).

### *5.7.2 Walking*

Another common outcome which was measured with significant improvement was walking. In the study by Cheng et al. (2015), the 6 minute walk test improved with significant difference in change in scores immediately after the 8 week treatment and one day after treatment (p =

0.006) and significant difference immediately after the 8 week treatment and three days after the treatment ($p = 0.012$). However, no significant change ($p = 0.907$) resulted between scores one day after treatment and three days after treatment. In Ibrahim et al.'s (2014) study, there was a significant difference ($p = 0.001$) in the WBV group and no significant difference ($p = 0.173$) in the control group after treatment in the 6 minute walk test. There was a significant difference ($p = 0.02$) between the control and WBV groups after treatment. No significant difference ($p = 0.416$) between the WBV and control groups in the TUG test was detected. This is further reinforced in Ibrahim et al.'s (2014) study where they stated that there was no significant change in either the WBV or the control, and no change between the WBV and control group (WBV : Control; $p = 0.755$: $p > 0.05$).

Using gait analysis systems, Lee and Chon (2013) and Ko et al. (2016) demonstrated significant improvement in walking in the WBV group. All gait parameters (speed, stride length, cycle time) improved significantly ($p = 0.001$) in the WBV group in the study by Lee and Chon (2013) whereas speed ($p = 0.035$) and step width ($p = 0.039$) only improved in the WBV group in the study by Ko et al. (2016). Using the paired t-test, Ko et al. (2016) showed significant improvement in the WBV group in gait speed ($p = 0.005$), step length ($p = 0.021$) and step width ($p = 0.002$) whereas the control group all had p values greater than 0.05.

Ruck et al. (2010) and Unger et al. (2017) also demonstrated a significant improvement in speed. A statistically significant difference between the WBV and control groups was of $p = 0.03$ (Ruck et al. 2010) and the p value less than 0.05 (Unger et al. 2017) in favour of the WBV groups. However, Unger et al.'s (2017) study showed that after 8 weeks the treatment effect in the WBV group was not maintained when compared to pre-treatment values ($p = 0.768$). This is supported by Cheng et al. (2015) where the walking gains decreased over time when the WBV training was stopped.

### *5.7.3 FUNCTION*

Two studies showed an improvement in motor function (Katusic 2013; Ibrahim et al. 2014) while two studies did not (Ruck et al. 2010; Stark et al. 2016). There was no significant difference ($p > 0.05$) in Dimension D of the GMFM ($p > 0.05$) between the WBV and control groups but there was a significant difference ($p < 0.05$) between the two groups with better results in the WBV group (Ibrahim et al. 2014). These results were further reinforced by Katusic et al. (2013) where the GMFM scores increased significantly in both the control and WBV groups (same as the previous study) as well as significant difference in change of scores ($p = 0.001$) in favour of the WBV group.

On the other hand, no significant differences were found in both domains D ($p =0.54$) and E ($p = 0.14$) of the GMFM (Ruck et al. 2010). This was supported by Stark et al. (2016) where they demonstrated that both control and WBV groups improved in their GMFM scores but no statistically significant difference ($p = 0.412$) was found between the two groups.

### *5.7.4 BMD*

El-Shamy and Mohamed (2012) found a significant difference ($p < 0.05$) in BMD in the femur, lumbar spine, and total body between control and WBV groups in favour of the WBV group. Wren et al. (2010) further reinforced this in their study where they stated that WBV increased cortical bone. They investigated the tibial diaphysis and cortical bone and nearly all moments of inertia increased significantly increased ($p </= 0.03$). They also investigated lumbar vertebrae number 3 which also increased significantly ($p < 0.001$). On the other hand, Ruck et al. (2010) found no significant difference in BMD at the lumbar spine between treatment and control groups and at the distal femur of the metaphysis, there had a decreased BMD in the control group and though there was an increase in the WBV group this change was not statistically

significant (p = 0.11). In contrast, a significant group difference (p = 0.03) between control and WBV groups resulted in decreased BMD in the WBV group at the diaphysis (region 3).

### *5.7.5 Spasticity*

Spasticity decreased significantly after WBV treatment. There was a significant difference in change scores immediately after WBV when compared to pre-treatment as well as three days post-treatment (p = 0.036) (Cheng et al. 2015). Moreover, Katusic et al. (2013) found that change in scores between the WBV and control group had a significant difference in the WBV group (p < 0.001) resulting that WBV decreased spasticity. In Tupimai et al.'s (2016), the MAS significantly improved in the WBV group in the soleus muscle of the weaker leg only when compared with the control group immediately after the first treatment session. After the 6 week study, the MAS improved in both the WBV intervention (all studied muscles improved in spasticity) and the control group (hamstring and soleus of the stronger side). When the two groups were compared, the MAS scores significantly improved in the quadriceps and hamstrings of both legs and the soleus only in the weaker leg in the WBV group.

## 5.8 Summary of Results and Risk of Bias

Out of six studies mentioned in section 5.7.1, four studies (Lee and Chon 2013; El-Shamy 2014; Ibrahim et al. 2014; Unger et al. 2017) concluded that muscle strength improved after WBV. The study by El-Shamy (2014) had a low risk of bias in the majority of the domains resulting in a high quality study. Ibrahim et al. (2014) and Unger et al. (2017) had a few domains with an unclear risk of bias which may have affected the results of their studies. The study by Lee and Chon (2013) has a low risk of bias, also present in the Detection Bias domain. In the study by

Lee and Chon (2013), participants were required to be able to walk without walking aids, whereas in the rest of the studies (El-Shamy 2014; Ibrahim et al. 2014; Unger et al. 2017) participants were required to be able to walk with or without walking aids. Both studies by El-Shamy (2014) and Ibrahim et al. (2014) had similar intervention parameters. In the study by Wren et al. (2010) the risk of bias is low, but in the Detection Bias domain the risk of bias is unclear which may affect the results. In the Selection Bias domain, only the studies by Wren et al. (2010) and El-Shamy (2014) had a low risk of bias for both sub-domains. In the study by Tupimai et al. (2016), the conclusions of the study are misleading since they state there was an increase in strength in the WBV group whereas in the results the authors reported an increase in strength in both groups but no significant difference between the control and WBV groups. This study had a mixture of unclear, low and high risk of bias which affects results. In all the above mentioned studies the participants needed to be able to walk with/out a walking aid or stand holding/not holding for 10 minutes. Therefore, it can be concluded that the results drawn from these studies did not include children with a GMFCS level V.

All the six studies mentioned in 2.7.2 concluded that there was an improvement in walking. The two studies by Cheng et al. (2015) and Ibrahim et al. (2014) an unclear risk of bias in most domains which affect the quality of the study and their results, thus need to be interpreted with caution. The study by Lee and Chon (2013) had a low risk of bias in most domains, whereas Ko et al.'s (2016) study had an unclear risk of bias in the Selection and Performance Bias domains and a high risk of bias in the Detection bias domain. In the study by Ruck et al. (2010) a high risk of bias was also found in the Detection bias domain. Unger et al. (2017) had a mixture of low and unclear risk of bias. Out of six studies, three studies (Ruck et al. 2010; Ibrahim et al. 2014; Ko et al. 2016;) had a similar protocol of WBV treatment with the latter two studies using the same frequency. All participants in the included studies were able to walk with or without a walking aid.

Two studies showed an improvement in motor function (Katusic 2013; Ibrahim et al. 2014;). Though Ibrahim et al.'s (2014) study had unclear risk of bias in many domains, Katusic et al. (2013) had a low risk of bias in most of the domains. The study by Katusic et al. (2013) is the only study which included children with a GMFCS level V. In the studies by Ruck et al (2010) and Stark et al. (2016) no improvement was found in the WBV groups. Some domains in the former study (Ruck et al. 2010) had a low risk of bias with one domain having a high risk of bias in the Detection bias domain, while in the latter study the majority had a low risk of bias (Stark et al. 2016). Both these studies and the study by Ibrahim et al. (2014) had similar protocols with few differences.

Though the majority of the domains have an unclear risk of bias in the study by El-Shamy and Mohamed (2012), the study by Wren et al. (2010) reinforce their findings in that WBV increases BMD. In the study by Wren et al. (2010) there was a low risk of bias in the majority of the domains. Though in the study by Ruck et al. (2010), a decrease in BMD was found in the WBV group, this study has a high risk of bias in Detection bias. In the studies by El-Shamy and Mohamed (2012) and Wren et al. (2010) the authors used a high frequency (30Hz) unlike the study by Ruck et al. (2010).

Though spasticity was found to have decreased in the WBV group and the Attrition and Reporting bias were low in the study by Cheng et al. (2015), the rest of the study had an unclear risk of bias. However, in the study by Katusic et al. (2013), spasticity was also found to have decreased and this study has an overall low risk of bias. In the study by Tupimai et al. (2016), spasticity was found to have decreased in the hamstrings and quadriceps. Though the Selection Bias was low in random generation, allocation concealment of the participants was unclear which may influence the results.

## 5.9 Conclusion

This chapter included the detailed process of the selection of the included studies chosen for this systematic review. Descriptive information of each study were extracted and described. The methodological quality of each study was then carried out and described. In conclusion, few studies had a generally low risk of bias. As already stated, the outcomes were not present in all of the studies. Walking and strength were the most frequent outcomes being measured.

# 6. DISCUSSION

# 6. DISCUSSION

This section includes the synthesis of the results of the twelve studies which were analysed. Apart from this, the limitations of this systematic review are discussed as well as recommendations for future research.

## 6.1 SYNTHESIS OF THE RESULTS

After the analysis of the twelve studies, synthesis of the results was carried out. A few key findings of the outcomes which were measured were drawn and discussed below. This systematic review was based on the effects of WBV on children with CP and how effective this treatment can be. WBV has been used as an adjunct to other therapy and not on its own.

### *6.1.1 STRENGTH*

It has been proven that dynamometers are reliable instruments to measure muscle strength of the knee extensors (Knols et al. 2009). In fact, this instrument was used in most studies to measure lower limb strength (Ibrahim et al. 2014; El-Shamy 2014; Wren et al. 2010). Lower limb strength was also measured by the time an individual can perform sit to stands for five times. This is a reliable tool to investigate lower limb muscle strength in children with CP (Kumban et al. 2013) which was used in the study by Tupimai (2016). The study by El-Shamy (2014) is a good quality study since most domains have a low risk of bias. On the other hand, Tupimai (2016) did not have a good methodological quality having reported an increase in strength in the WBV group when compared to the control group which was not consistent with the results obtained from the study. Wren et al. (2010) also found no difference in strength after WBV

between groups. These results are in conflict with what other studies found (Saquetto et al. 2015). Conflicting evidence was found, with four studies (Lee and Chon 2013; Ibrahim et al. 2014; El-Shamy 2014; Unger et al. 2017) stating that WBV may improve strength. Using ultrasonography, Lee and Chon (2013) and Unger et al. (2017) also found an increase in thickness in the Tibialis Anterior and soleus muscle and abdominal thickness. These results agree with other studies such as Stark et al. (2010) and Ahlborg et al. (2006). However, the latter study included adults with CP instead of children which may affect the results. These results contrast with the results of the systematic review with meta-analysis by Saquetto et al. (2015) where they found no significant effect in muscle strength. However, Saquetto et al. (2015) only included three studies for analysis which is a very low number.

Different protocols for WBV were used and out of six studies, only one study with a low risk of bias in most domains stated there was no increase in strength between the WBV and control groups (Wren et al. 2010). The other study did not have good methodological quality (Tupimai et al. 2016). All the studies only included participants with a GMFCS level lower than V, therefore, these results need to be interpreted with caution and cannot be generalized to the whole population of CP. Therefore, though WBV may improve muscle strength, this interpretation must be very cautious due to the mixture of quality of evidence of the studies included as can be seen in Section 5.8.

### *6.1.2 WALKING*

High test-retest reliability was found in children with CP for the 6-minute walk test (Maher et al. 2008). The improvement in walking speed using this test was found in two studies (Ibrahim et al. 2014; Cheng et al. 2015) with a significant difference between the WBV and control groups in favour of the WBV group. Both studies had an unclear risk of bias in most of the domains of

the Cochrane Risk of Bias tool thus results should be interpreted with caution. On the other hand, the study by Lee and Chon (2013) resulted in improved walking between groups in favour of the WBV group and has a low risk of bias in most of the domains. This study used a 3D gait analysis which is a gold standard in measuring gait. Ruck et al. (2010) and Ko et al. (2016) also measured improvements in walking in the WBV group when compared to the control group but both had a high risk of bias in the Detection Bias thus results need to be interpreted with care. Unger et al. (2017) had a younger population of participants and also resulted in improved walking. These results agree with the systematic review with meta-analysis by Saquetto et al. (2015) that WBV improves walking.

The TUG test's reliability has been studied and found to be reliable in children with CP. (Dhote et al. 2012). Two studies (Cheng et al. 2015; Ibrahim et al. 2014) used this test but no significant difference was detected between the WBV and control groups after treatment.

All participants in the selected studies were able to walk with or without a walking aid. Therefore, these results cannot be generalized to children with CP with a GMFCS level V. All participants needed to be able to comprehend and follow instructions thus excluding children with severe cognitive impairment.

### *6.1.3 Function*

The four studies which measured motor function showed conflicting results (Ruck et al. 2010; Katusic et al. 2013; Ibrahim et al. 2014; Stark et al. 2016). The studies by Ibrahim et al. (2014) and Katusic et al (2013) concluded that WBV improves motor function in children with CP. The former study (Ibrahim et al. 2014) had a moderate quality of evidence with most domains having an unclear risk of bias which may affect the results since the data given was not clear. Selection Bias, Performance Bias and Detection bias were rated as having an unclear risk of bias due to

the authors not giving sufficient information. The latter (Katusic et al. 2013) was a good quality study with most of the domains having a low risk of bias. These results agree with other studies by Gusso et al. (2016) and Stark et al. (2010). This positive improvement was also stated in the systematic review by Saquetto et al. (2015). However, in the systematic review by Saquetto et al. (2015) only three studies were included and all had a positive effect. However, in this systematic review four studies were included with two studies having conflicting results with the other two. The studies by Ruck et al. (2010) and Stark et al. (2016) showed no significant differences in improvement between the WBV and control groups. In the study by Ruck et al. (2010) a small sample size of twenty participants was used and in the study by Stark et al. (2016) a very young population (1-2 years) was used and thus it is difficult to compare results with other studies which have an older age population. In all the studies, the GMFM was used which is a reliable and valid tool to measure gross motor function (CanChild 2018).

### *6.1.4 BMD*

Three studies were found which measured BMD in children with CP (Ruck et al. 2010; Wren et al. 2010; El-Shamy and Mohamed 2012). In the systematic review by Saquetto et al. (2015) an improvement in BMD in the femur but not in the lumbar spine was found. However, this review resulted in conflicting evidence.

El-Shamy and Mohamed (2012) and Wren et al. (2010) found a significant difference in BMD in the femur and lumbar spine. On the other hand, Ruck et al. (2010) found no significant difference in BMD at the lumbar spine, which coincides with the conclusions by Saquetto et al. (2015). Though there was an increase in the WBV group when compared to the control group at the distal femur this change was not statistically significant ($p = 0.11$). In contrast, a significant

group difference (p = 0.03) between control and WBV groups resulted in decreased BMD in the WBV group at the diaphysis (region 3).

The study by El-Shamy and Mohamed (2012) had unclear risk of bias in the majority of the domains, thus results should be interpreted with caution. On the other hand, the study by Wren et al. (2010) had a low risk of bias in the majority of the domains, resulting in a higher methodological quality study and thus reinforcing the results obtained by El-Shamy and Mohamed (2012). The study by Ruck et al. (2010) resulted in a decrease in BMD in the WBV group. However, this study has a high risk of bias in Detection bias and an unclear risk of bias in two other domains which may affect results. It is important to note that in the studies by El-Shamy and Mohamed (2012) and Wren et al. (2010) the authors used a higher frequency (30Hz) of vibration while Ruck et al. (2010) used a lower one (12-18Hz) which may have affected the results. Bone changes according to the diverse loading conditions. Therefore, frequencies between 15-35 Hz are used to obtain the best maximal mechanical load given by the vibrating plate (Rubin et al. 2004). It could be that if Ruck et al. (2010) had used a higher frequency of vibration, different results would have been obtained.

### *6.1.5 SPASTICITY*

Four studies found that whole body vibration exercises decreased spasticity in children with CP (Katusic et al. 2013; Ibrahim et al. 2014; Cheng et al. 2015; Tupimai et al. 2016). This is consistent with other previous research (Sa'-Caputo et al. 2014; Duqette et al. 2015).

In order to measure spasticity the MAS is most commonly used. However, though the reliability of the MAS was found to be good the validity was not (Bohannon and Smith 1987; Pandyan et al. 2003). On the other hand, the MMAS was found to have good reliability and validity (Ghotbi

et al. 2011). Out of the three studies only the study by Katusic et al. (2013) used the MMAS while the others used the MAS.

After WBV, a significant difference in the change scores was found in all the studies after the procedure in favour of the WBV group. In the study by Katusic et al. (2013), a low risk of bias was found in all domains with only one domain (Allocation concealment) having an unclear risk of bias. This leads to a high quality study with reliable results. On the other hand, the study by Cheng et al. (2015) had all domains except one with an unclear risk of bias. Therefore, results should be interpreted with caution. Though the study by Tupimai et al. (2016) also resulted in decreased spasticity in the hamstrings and quadriceps in the WBV group when compared to the control group, these results also should be interpreted with caution. Though the Selection Bias was low in random generation, allocation concealment of the participants and detection bias were unclear which may have influenced the results. In the study by Ibrahim et al. (2014), most domains also had an unclear risk of bias.

Sample sizes were small for the studies by Cheng et al. (2015) and Tupimai et al. (2016). Moreover, the types of participants were quite similar with a GMFCS level between I-III. On the other hand, the study by Katusic et al. (2013) had a much larger sample size (89 participants) and a mixture of children with GMFCS levels from II-V, with it being the only study which included children with a GMFCS level V. Therefore, generalisation of results may be done.

## 6.2 Blinding of Participants and Assessors

Blind procedures are common in studies, so that knowledge from the assessor and participants may not affect the results. The vast majority of the studies included had an unclear risk of bias in the performance bias domain and a mixture of high, low and unclear risk of bias in the detection bias domain. Therefore, it is possible that the results of the included studies are affected by not having correct blinding procedures.

## 6.3 Recruitment

The majority of study participants were recruited from one of the following: special education schools, a local hospital, an outpatient clinic and a day-care centre. Only one study (Cheng et al. 2015) recruited participants from two locations. This suggests that the sample population in the study may not be representative of the population since children with CP are not all found at a special education school, local hospital, outpatient clinic or day-care centre. Therefore, this may lead to potential bias in the results of the studies obtained.

## 6.4 Sample size

The effect of WBV in children with CP was investigated in 363 participants which is the total number of participants in the selected studies included in this review. The prevalence of children with CP is 2.11 per 1000 live births in the world (Odding et al. 2006). Some studies had a sample size as few as twelve participants which is not representative of the population.

## 6.5 Differences between Included Studies

There were various differences in the twelve studies selected for this review which may affect results. The WBV protocol used was different in most of the studies with only four studies having similar protocols. The parameters were also different in most studies. These may affect the results and conclusions of the studies due to obtaining different results for the same study aim. Apart from this, since the studies included participants from different parts of the world, having different physiotherapy programmes and WBV protocols may lead to inconsistencies in results.

Another difference is in the control group. In the comparison group, the participants received either physiotherapy or continued with their usual daily regimen. However, differences in the physiotherapy programmes and daily routine in children with CP across the globe as well as in the same country may have affected the results.

Finally, the outcome measures used to assess the effect of WBV on the different outcomes measured were different in many of the selected studies. Consequently, many times results could not be compared

## 6.6 Strengths and limitations of the review

Several strengths and limitations of this review are discussed below. Several databases were selected to ensure the most relevant retrieval of potential studies. The reference lists of the chosen studies were also hand-searched to ensure no studies are missing. However, the process of study selection was carried out by a single researcher. This may result in accidentally overlooking potential articles during the screening process. Only studies available in the English language were included in this study due to the unavailability of a translator.

Consequently, this may have resulted in the exclusion of key articles which could have been included in this review. During the search process, two short reports which were presented during a conference showed up. However, the unavailability of the full texts of the studies resulted in these being rejected from this review, though their results could have been relevant for this review. Apart from this, methodological quality of the articles was assessed by only one researcher using The Cochrane Risk of Bias tool for assessing risk of bias which may have resulted in bias while rating the studies. Having another reviewer for both the process of study selection and to assess the methodological quality would have ensured no studies were missed during the study selection process and less bias whilst assessing the methodological quality by discussing any domains which may have been rated differently by the different reviewers. Therefore, another reviewer would increase the reliability of the results obtained.

All of the reviewed studies examined the effects of WBV together with daily routine/standard therapy. Therefore the results of these studies could not be attributed solely to WBV therapy and the other therapy may have affected the results of this review.

The results of this study are only applicable to children with CP.

## 6.7 Implications for practice and future research

The systematic review allows us to understand the effectiveness of WBV. However, no studies included how to maintain the positive results in the long-term. Therefore, longitudinal studies would be recommended to be carried out to determine the effects of WBV over time. Larger sample sizes with children of all GMFCS levels are also recommended to ensure that the participants are representative of the CP population.

Further studies could be conducted to determine the most appropriate mode (frequency, amplitude, duration etc.) to target each outcome.

Furthermore, this systematic review involved studies with unclear or high risk of

Performance and Detection bias, and thus, future studies should attempt to have more studies with a low risk of bias so that results are less biased and more valid. Therefore, further studies are recommended with high quality study designs.

Moreover, the extent of the impact of the intervention on strength, BMD, function and spasticity are still inconclusive, therefore, future studies are needed to address these outcomes. Apart from this, further studies need to be conducted which address children with CP with GMFCS level V.

Finally, although WBV exercises have shown significant improvements in walking post-treatment, the sample populations were able to walk with or without a walking aid. Therefore, future studies may include children with CP who are more profoundly affected (GMFCS level V).

The results of this systematic review suggest that WBV have a positive effect on walking and may improve strength in children with CP. However, these results have included studies with a variety of research methodological quality and therefore, results should be interpreted with caution. Further studies with better methodological quality should be carried out to address strength.

On the other hand, though the results from this review show that WBV seems to improve spasticity, further research is needed with high quality designs, a better outcome measure and a larger sample size, since only a few studies measuring spasticity were included. Few studies were included which measured BMD. However, more studies are needed to be conducted while using a high frequency for more positive results. Moreover, further research is needed to measure motor function due to the conflicting evidence found.

# 7. CONCLUSION

## 7.1 CONCLUSION

After a comprehensive search, twelve studies were selected for this review. The studies were a mixture of low, unclear and high risk of bias. WBV therapy is used as an adjunct to physiotherapy treatment and never on its own. This review suggests that WBV improves walking. It may also improve muscle strength in children with CP who already walk with or without a walking aid. However, further high quality research is recommended to validate improvement in muscle strength. WBV seems to improve spasticity and BMD but further high quality studies need to be conducted in order to validate this. Conflicting evidence for function has been found, therefore, further studies are recommended in order to be able to draw conclusions.

**Word count:** 13, 103

# 8. REFERENCES

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# 9. APPENDICES

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## APPENDIX 1: THE COCHRANE RISK OF BIAS ASSESSMENT TOOL

| Domain | Support for judgement | Review authors' judgement |
|---|---|---|
| *Selection bias.* | | |
| **Random sequence generation.** | Describe the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups. | Selection bias (biased allocation to interventions) due to inadequate generation of a randomised sequence. |
| **Allocation concealment.** | Describe the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen in advance of, or during, enrolment. | Selection bias (biased allocation to interventions) due to inadequate concealment of allocations prior to assignment. |
| *Performance bias.* | | |
| **Blinding of participants and personnel** *Assessments should be made for each main outcome (or class of outcomes).* | Describe all measures used, if any, to blind study participants and personnel from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective. | Performance bias due to knowledge of the allocated interventions by participants and personnel during the study. |
| *Detection bias.* | | |
| **Blinding of outcome assessment** *Assessments should be made for each main outcome (or class of outcomes).* | Describe all measures used, if any, to blind outcome assessors from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective. | Detection bias due to knowledge of the allocated interventions by outcome assessors. |
| *Attrition bias.* | | |
| **Incomplete outcome data** *Assessments should be made for each main outcome (or class of outcomes).* | Describe the completeness of outcome data for each main outcome, including attrition and exclusions from the analysis. State whether attrition and exclusions were reported, the numbers in each intervention group (compared with total randomized participants), reasons for attrition/exclusions where reported, and any re-inclusions in analyses performed by the review authors. | Attrition bias due to amount, nature or handling of incomplete outcome data. |
| *Reporting bias.* | | |
| **Selective reporting.** | State how the possibility of selective outcome reporting was examined by the review authors, and what was found. | Reporting bias due to selective outcome reporting. |
| *Other bias.* | | |
| **Other sources of bias.** | State any important concerns about bias not addressed in the other domains in the tool.<br>If particular questions/entries were pre-specified in the review's protocol, responses should be provided for each question/entry. | Bias due to problems not covered elsewhere in the table. |

# APPENDIX 2: RISK OF BIAS ASSESSMENTS

| Effects of an 8 week WBV on lower extremity muscle tone (Cheng et al. 2015) | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Unclear risk | Author stated that the group was randomised but did not outline how randomisation occurred |
| Allocation Concealment | Unclear risk | Study did not state if patients were concealed to a particular treatment |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Authors declined to address this issue |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Unclear risk | Although authors mentioned that there was a cross over followed by a 4 week wash out period, nothing is mentioned regarding blinded assessors/participants |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low Risk risk | Group was divided equally into two. Although drop-outs of patients are not mentioned there is a low chance of this happening as duration of study was short (16 weeks) |
| *Reporting bias* | | |
| Selective Reporting | Low Risk risk | Protocol included in this study and the outcomes mentioned in this section were all reported in the article. (including walking [6MWT] + [MAS]) |

| Effect of Whole of Whole Body Vibration Training on Bone Mineral Density in Cerebral Palsy Children (El-Shamy and Mohamed 2012) | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | Sufficient detail given for random allocation. The author used "sealed envelopes". |
| Allocation Concealment | Low risk | Allocation to the group was given before the first assessment and "sealed envelopes" were given to the participants. |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | The children receiving the treatment of WBV could not be blinded. It was not mentioned whether the administrator was blinded |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | "Baseline and posttreatment assessments were performed for all children by a single blinded examiner" |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | No drop-outs from the study. Participants were excluded if they did not meet inclusion criteria and if they refused to participate. A Flow diagram in Figure 1 "showing the children participating in this study" and the number of children analysed in the end of the study. Baseline and posttreatment assessments were performed for all children. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | The study procedure is available. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| Effects of Whole-Body Vibration on Muscle Strength and Balance in Diplegic Cerebral Palsy (El-Shamy 2014) | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | Sufficient detail given for random allocation. The author used "sealed envelopes". |
| Allocation Concealment | Low risk | Allocation to the group was given before the first assessment and "sealed envelopes" were given to the participants. |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | The children receiving the treatment of WBV could not be blinded. It was not mentioned whether the administrator was blinded |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | "Baseline and posttreatment assessments were performed for all children by a single blinded examiner" |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | No drop-outs from the study. Participants were excluded if they did not meet inclusion criteria and if they refused to participate. A Flow diagram in Figure 1 "showing the children participating in this study" and the number of children analysed in the end of the study. Baseline and posttreatment assessments were performed for all children. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | The study procedure is available. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| Effect of whole-vibration on muscle strength, spasticity, and motor performance in spastic diplegic cerebral palsy children (Ibrahim et al. 2014) | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Unclear risk | There was insufficient information since though the authors mentioned that participants were "randomized to intervention", they did not go into detail into how they were randomized. |
| Allocation Concealment | Unclear risk | Not described in the study |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Author declined to mention this issue. However, it is difficult to blind participants and personnel due to the whole body vibration system. |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Unclear risk | "All the tests were performed before and after the 12-week treatment period" but no mention of blinding was given |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | All the outcomes were reported in the study: "The mean values of isometric strength, spasticity, walking speed and balance, and motor development obtained before and after 12-weeks treatment in both groups were compared…" |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Protocol/procedure have been mentioned: "All the tests were performed before and after the 12-week treatment period" with all the outcome measures being mentioned in the study results. |
| *Other bias* | | |
| Other Sources of Bias | Low risk | "The authors declare no conflict of interest or funding for this research". |

| The Effect of Vibration Therapy on Spasticity and Motor Function in Children with Cerebral Palsy: a Randomized Controlled Trial (Katusic et al. 2013) | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | Participants where stratified randomly "to ensure similar function levels in both groups" using the GMFCS. |
| Allocation Concealment | Unclear risk | Insufficient information |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Low risk | The physiotherapist providing physiotherapy was blinded "to the group allocation of children" |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | Two experienced physiotherapists performed the tests were "blinded to treatment allocation". |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | Participants lost/not included in the final study are stated in the method section. The remaining 89 participants were divided. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Both the primary and secondary outcomes that are relevant to the study were addressed. |
| *Other bias* | | |
| Other Sources of Bias | | |

| **Effect of Three Weeks of Whole-Body Vibration Training on Joint-Position Sense, Balance and Gait in Children with Cerebral Palsy: A Randomized Controlled Study (Ko et. al. 2016)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Unclear risk | Randomization is mentioned but not in sufficient detail. |
| Allocation Concealment | Unclear risk | The authors did not mention allocation concealment |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Not mentioned by authors |
| *Detection bias* | | |
| Blinding of Outcome Assessment | High risk | The authors mentioned "we evaluated…" during outcome measures but did not mention that they were blinded. |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | Number of drop-outs was reported "… but 2 dropped out…"<br>All outcomes mentioned to be measured were evaluated before and three weeks after treatment. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Protocol is available in the study and all outcomes have been reported. |
| *Other bias* | | |
| Other Sources of Bias | | |

| **Effect of whole body vibration training on mobility in children with cerebral palsy: a randomized controlled experimenter study (Lee and Chon 2013)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Unclear risk | "Randomization was performed using sealed envelopes." But the process is not described in detail. |
| Allocation Concealment | Low risk | "A piece of paper in the sealed envelope was given to the participants for group allocation. Allocation occurred before the initial assessment." |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear | Blinding is difficult due to the WBV system. The authors did not mention blinding for this domain. |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | "The physiotherapists undertaking the outcome assessment were also blinded to group allocation." |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | All outcomes were measured in Results section.<br>No participants dropped out. Before the intervention was given, two participants refused to participate. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Protocol described within methods section and all outcomes were assessed pre- and post- intervention. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| **Vibration treatment in cerebral palsy: a randomized controlled trial (Ruck et al. 2010)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Unclear risk | Random stratified sampling to have similar levels in both groups. However, insufficient information given. |
| Allocation Concealment | Low risk | Following the baseline evaluation of each child, a closed envelope was randomly selected that contained the child's allocation. |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Not mentioned in the study. Not possible to blind the participants and personnel since "the vibration produced by the device is easily observable" |
| *Detection bias* | | |
| Blinding of Outcome Assessment | High risk | "The assessments were performed by one of the investigators (J.R.) who at the time of the second evaluation was unblinded as to treatment allocation" |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | Participants who did not complete the study were mentioned (three from the control group). |
| *Reporting bias* | | |
| Selective Reporting | Low risk | All outcomes mentioned were measured and reported in the results section. Procedure/protocol and paper were the same. |
| *Other bias* | | |
| Other Sources of Bias | | |

| **Early vibration assisted physiotherapy in toddlers with cerebral palsy – a randomized controlled pilot trial (Stark et al. 2016)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | "Block randomization (blocks of 2 and 4) was performed by SAS 9.1. SAS is a computer programme random number generator |
| Allocation Concealment | Low risk | "The participants were randomized (using closed envelopes) into two groups with equal numbers. |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | "Because of the nature of the intervention, participants could not be blinded to the treatment." |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | "The physiotherapist completing the assessments was blinded to intervention" |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | "No drop-outs or loss to follow-up" (Figure 3 in study)<br>Outcome of gross motor function was measure and reported. |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Study protocol is available and study followed protocol. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| **Effect of combining passive muscle stretching and whole body vibration on spasticity and physical performance of children and adolescents with cerebral palsy (Tupimai et al. 2016)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | "Sampling randomization was stratified…"<br>"The GMFCS levels and ages were similar in both groups…" |
| Allocation Concealment | Unclear risk | Insufficient information given |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Insufficient information given |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Unclear risk | Insufficient information given |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk of bias | No drop-outs from the study. All the outcomes mentioned were measured. |
| *Reporting bias* | | |
| Selective Reporting | High | Tupimai states that there is an increase in strength in the WBV group but this was also found in the control group and no significant statistical difference was found between the control and WBV groups. However, the study concludes that WBV improves strength. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| **Effect of a trunk-targeted intervention using vibration on posture and gait in children with spastic type cerebral palsy: A randomized control trial (Unger et al. 2017)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | The participants were "randomly assigned to the different intervention groups using excel generated random numbers". |
| Allocation Concealment | Unclear risk | Insufficient information to permit judgement |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | The author did not mention blinding. |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Low risk | One of the investigators who assessed the 1 minute fast walking test "was blinded as to which subjects participated in either of the two arms of the study" |
| *Attrition bias* | | |
| Incomplete Outcome Data | Unclear risk | No drop-outs mentioned |
| *Reporting bias* | | |
| Selective Reporting | Low risk | The protocol/procedure is mentioned and all outcomes were reported. |
| *Other bias* | | |
| Other Sources of Bias | Unclear risk | |

| **Effect of High Frequency, Low Magnitude Vibration on Bone and Muscle in Children with Cerebral Palsy (Wren et al. 2010)** | | |
|---|---|---|
| Check List | Judgement | Support for Judgement |
| *Selection bias* | | |
| Random Sequence Generation | Low risk | "Participants were randomized…using computer-generated group assignments…" |
| Allocation Concealment | Low risk | "…implemented using sealed envelopes" |
| *Performance bias* | | |
| Blinding of Participants and Personnel | Unclear risk | Insufficient information on blinding, which is difficult due to WBV system. |
| *Detection bias* | | |
| Blinding of Outcome Assessment | Unclear risk | Authors did not mention blinding of outcome assessment |
| *Attrition bias* | | |
| Incomplete Outcome Data | Low risk | All outcomes mentioned were mentioned in results |
| *Reporting bias* | | |
| Selective Reporting | Low risk | Drop-outs were reported. |
| *Other bias* | | |
| Other Sources of Bias | | |